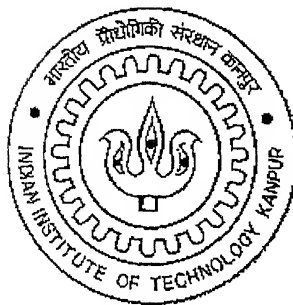# Performance of Metal Monolith Catalytic Converter on Kerosene fuelled Spark Ignition Engine Genset, using Secondary Air Injection

by
Dharmendra Singh

DEPARTMENT OF MECHANICAL ENGINEERING
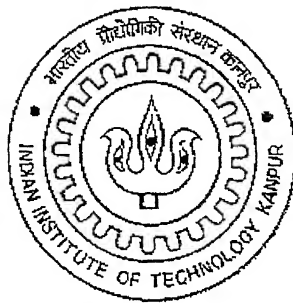
INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

December, 2002

Performance of Metal Monolith Catalytic Converter on Kerosene fuelled Spark Ignition Engine Genset, using Secondary Air Injection

A Thesis Submitted
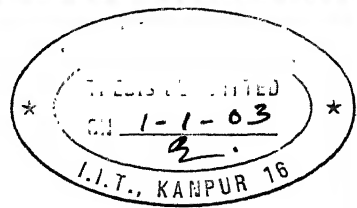In Partial Fulfillment of the Requirements
for the Degree of

Master of Technology

by

Dharmendra Singh

DEPARTMENT OF MECHANICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, KANPUR
December, 2002

CERTIFICATE

It is certified that the work contained in this thesis entitled.

Performance of Metal Monolith Catalytic Converter on Kerosene fuelled Spark Ignition Engine Genset using Secondary Air Injection by **Dharmendra Singh** has been carried out under the supervision of the undersigned. This work has not been submitted elsewhere for the award of a degree.

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Dedicated to

My Parents

Brother and Sisters

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Chapter 1   Introduction

Chapter 2   Experimental Set-up and Methodology

Chapter 3   Calculations of Mass Emissions

Chapter 4   Results and Discussions

Abstract

Emission regulation for portable gensets have been enforced in India from June 2000 and tightened further from June 2001. To meet the future standards, after-treatment of engine exhaust may be required in addition to engine optimization.

The 4-stroke kerosene fuelled spark ignition (SI) engine genset are widely used and operate at rich mixture conditions thereby emitting high amount of unburned carbon dioxide (CO) and unburned hydrocarbons (HC).

In the Present study, application of a monolith, oxidation catalytic converter on a 4-stroke kerosene fuelled SI engine genset was investigated. The catalytic converter was installed inside the muffler. Only negligible reductions in CO and HC emissions were observed without secondary air injection (SAI). The performance of catalytic converter on this generator set was studied with the use of SAI adopting different SAI methods. With the reed valve and venturi fitted in the exhaust pipe upstream of converter the desirable reductions in CO and HC emissions were not obtained. To achieve significant reductions, a blower was used for SAI with the use of blower, sufficient secondary air could be introduced. With this arrangement, the CO conversion efficiency obtained, range from 80.91% to 93.42% and HC conversion efficiency range from 37.77% to 53.38%.

This study concluded the emission standards for portable gensets can be further tightened and can be met with the use of oxidation catalytic converters.

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CHAPTER 1

INTRODUCTION:

Today, due to increase in power generation from fossil fuels, industrial activities and vehicles, there is a significant increase in environmental pollution. The internal combustion engine is now known to be major source of unburned hydrocarbons, carbon monoxide and oxides of nitrogen emissions into atmosphere. These pollutants affect not only human health but also animal, plants and materials.

The power requirements in India, a fast developing country is increasing at a high rate. But due to lack of investment and resources, power production is lagging far behind the requirement, resulting into frequent power cut off in all the sectors of activities. To overcome this problem, more and more captive power generators are being used by the industry, traders and in domestic sectors. In the marketplace and residential areas, small portable generator-sets are commonly used. Generally, the portable generators used in residential areas are powered either by small gasoline fuelled 2- stroke SI engines or kerosene fuelled 4-stroke, SI engines. In some cases, diesel powered generator-sets are also used. These small SI engines run at rich mixture conditions, which leads to inefficient combustion and high-unburned hydrocarbon and carbon monoxide emissions.

In India, vehicle emissions standard were enforced for the first time in 1990-91, which were lowered in April 1996 and 2000. Even tougher standards are being

proposed during this decade [Pundir, 1997]. Emission standards for portable generator sets up to 19kW output were enforced foe the first time in June 2000 and again tightened in June 2001 [Pundir et al 2001].

During the last decade [Sesselmann et. al. 2001], a further tightening of emission norms was seen as a measure to curb increasing pollution in major countries including India (Fig: 1.1) It needs to be mentioned [Sesselmann et. al. 2001] that, out of total exhaust flow from of an engine, 98% is non-harmful (Fig: 1.2). Only the remaining 2% need to be treated with a catalyst, to convert harmful gases into non-harmful gases.
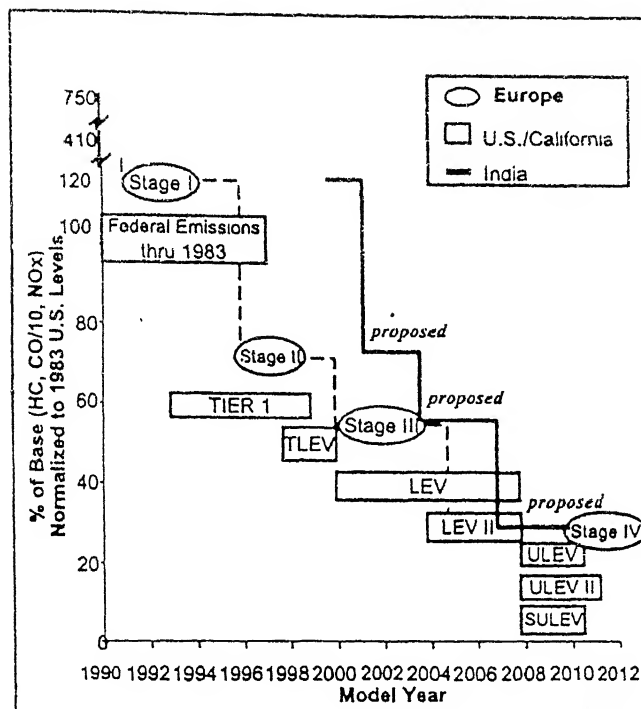
Fig: 1.1   Emissions Evolution U.S., Europe, India
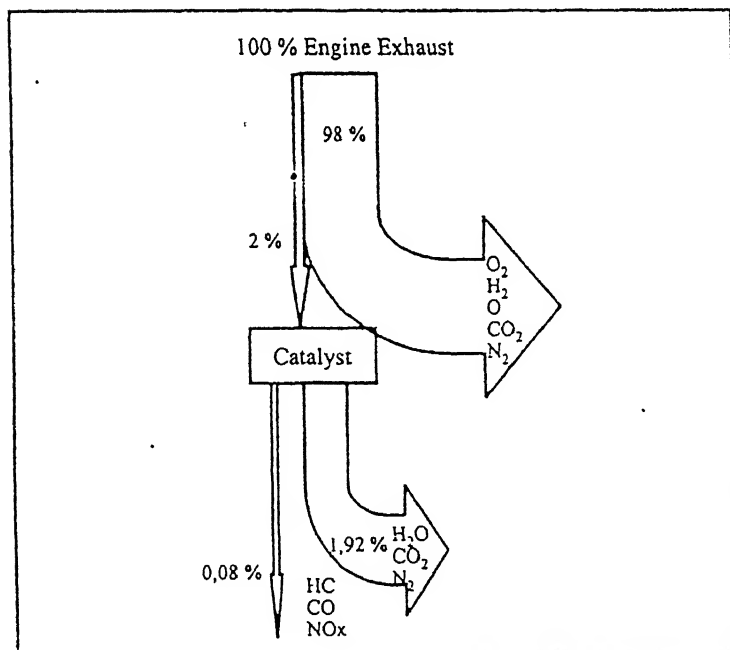
Fig: 1.2   The Automotive Catalyst - Function

1.1 EMISSION STANDARDS FOR PORTABLE GENERATORS:

SI Engine Generator-sets

Emission standards enforced by government of India (Central Pollution Control Board, Ministry of Environment and Forests, 1999) for new production generators-sets (up to 19KVA) run on petrol and kerosene are given in the Table 1.1, the emission standards are likely to tightened further in future.

Table 1.1

Emission Standards for Portable SI Engine Generator sets of upto 19kw in India

A. From June1, 2001

Class	Displacement(cc)	CO (g/kW-hr)		HC+NOx (g/kW-hr)	
		2-Stroke Engine	4-Stroke Engine	2-Stroke Engine	4-Stroke Engine
1	≤65	603	623	166	65.0
2	>65 ≤99	-	623	-	36.0
3	> 99 ≤225	-	623	-	19.3
4	>225	-	623	-	16.1

B. From June 1,2001

Class	Displacement(cc)	CO (g/kW-hr)	HC+NOx (g/kW-hr)
1	≤65	519	54.0
2	>65 ≤99	519	36.0
3	> 99 ≤225	519	16.1
4	>225	519	13.4

The present standards are being met through engine design modifications and optimization of fuel and injection systems. In future, however, it may not be possible to meet the standards without catalytic converters. Even the June 2001 standards are not likely to be met by the 2-stroke SI engine generators without the use of catalytic converters.

1.2 DIFFERENT MODELS OF SI ENGINE PORTABLE GENSETS:

Two principal manufacturers of the SI engine portable generator-sets in India are M/s Birla Yamaha and Honda Siel Power Products. Technical specifications of some of their products are given in Table 1.2 – 1.4.

Table 1.2

Salient Technical Specifications of Portable Gensets Manufactured by Birla Yamaha (Two Stroke Engine)

Name of the Manufacture	Gen-Set Rating (Two-Stroke Engine)		
	LG 600 AC Model	LG 900 AC Model	BY 850 K
	400W	650	610
Type of fuel	Petrol	Petrol	Kerosene
Specific fuel Cons. (lit/kW-hr)	1.17	0.96	1.065
Fuel Cons. (lit/hr)	0.47	0.63	0.65
Volumetric Displacement (cc)	49.9	63.1	63.1

Table 1.3

Salient Technical Features of Portable Gensets Manufactured by Birla-Yamaha (Four –Stroke Engines)

	1000K	LG 2000A	LG2800	LG300	D 3000 S
Gen-Set rating	1000	1400	2000	2200	2200
Type of Fuel	Kerosene	Kerosene	Kerosene	Petrol	Petrol
Specific Fuel Cons. (lit/hr)	1.3	1.0	1.1	0.8	0.45
Fuel Cons. (lit/hr)	1.3	1.4	2.2	1.8	1.0
Volumetric Disp. (cc)	179	179	256	256	-

Table 1.4

Salient Technical Features of Portable Gensets Manufactured by Honda-Siel Power Products (Four Stroke Engines)

	EM 250	E 650 L	EBK 2000	E 2000 AC	EB 1000 K	EBK 2200	EBK 2800 S	EBK 1200	EBK 2000 AC
Set rating	360	360	1120	1120	520	1360	1680	800	1680
Specific Fuel Cons.(lit/k W-hr)	1.04	1.04	0.96	0.96	1.07	0.88	0.95	1.25	2.0
Fuel Cons.(lit./hr)	0.47	0.47	1.35	1.35	0.7	1.50	2.0	1.25	2.0
Volumetric Disp. (cc)	76	76	197	197	97	197	272	197	272

1.3 CATALYTIC CONVERTERS:

What is a catalytic converter?

The three principal harmful pollutants emitted by a SI engine are

* Carbon mono oxide (CO)

* Hydrocarbon (HC)

* Nitrogen oxide (NO_x)

CO is a poisonous gas for any breathing living being, NOx lead the photochemical smog and HC together on reacting and host of harmful secondary pollutants and acid rain and HC produces smog.

A catalytic converter is a device that uses an active catalyst to convert the harmful compounds in the engine exhaust gases into harmless compounds. The catalyst material employed for CO and HC oxidation and NO_x reduction must be distributed over a large surface area so that mass transfer characteristic between gas phase and active catalyst surface area is sufficient to allow close to 100 percent conversion with high catalytic activity.

How does it work?

In a catalytic converter, the catalyst (a mixture of Platinum, Palladium and Rhodium) is dispersed on ceramic metallic honeycomb or alumina pallets that are housed in a muffler, fitted into exhaust pipe. The catalyst support is washcoated with alpha-alumina to create a large surface area for dissipation of the active catalyst. This converts the HC into CO_2 and H_2O, CO into CO_2 It also converts NO_x back into N_2 and O_2, if reduction catalyst is employed.

1.3.1 OXIDATION CATALYTIC CONVERTERS:

The oxidation catalyst oxidizes CO and HC to CO_2 and water in the exhaust gas. About half the hydrocarbons emitted by a SI engine are unburned fuel components. The saturated hydrocarbons (which comprise some 20 to 30 percent) are most difficult to oxidize. The ease of oxidation increases with increasing molecular weight. Sufficient O_2 must be present to oxidize the CO and HC to CO_2 and H_2O.

The excess oxygen required may be supplied by engine itself running lean of stoichiometric or by injection of secondary air upstream of the catalytic converter. Because of their high intrinsic activity, noble metals are most suitable as catalytic material. They show higher specific activity for HC oxidation, are more thermally resistant to loss of low temperature activity, and are much less deactivated by sulphur in the fuel than metal oxides. Pure noble metals sinter rapidly in the 500°C to 900°C temperature range experienced by exhaust gases .A mixture of platinum (Pt); palladium (Pd) in 2:1 ratio are most commonly used. The particle size of the noble metal particles in a fresh catalyst is less than 50 nm.

Contemporary oxidation catalytic converter are available in two forms– a ceramic or a metallic monolith converter each performing the same function. Earlier, pelleted catalytic converters were employed the monolith converter in the mid-1980s took over entire market because of its compactness, lighter weight and quick warm up and response.

OXIDATION REACTION MECHANISM:

The oxidation catalyst applied to 4-stroke SI engines always almost require a system for adding air (oxygen) to the engine exhaust by means of an air pump or pulse air valve. Fig: 1.3 is a representation of the carbon monoxide reaction on the catalytic surface.

EXHAUST GAS STREAM

CO diffuses into porous matrix

O_2 chemisorbs onto catalytic site

CO_2 desorbs and enters exhaust stream

CERAMIC WALL OF MONOLITH
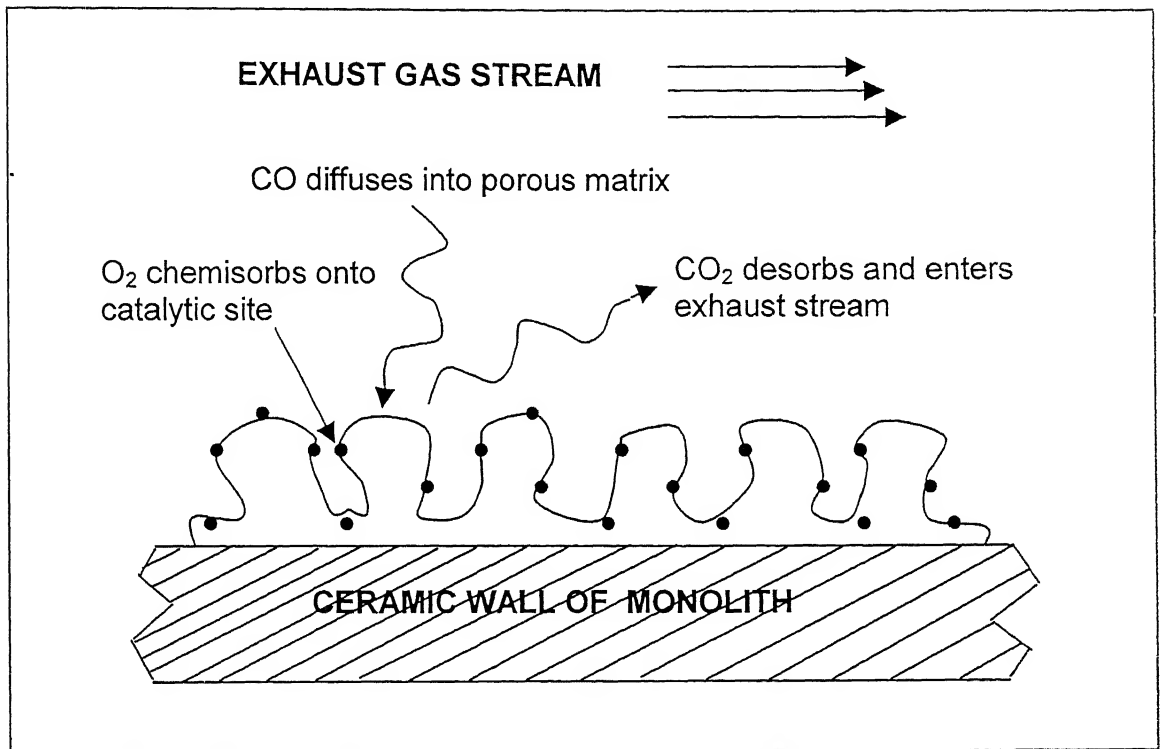
Fig: 1.3 Oxidation reaction on catalytic surface

First oxygen molecules diffuse from main stream to the catalyst site which is temporarily unoccupied. The oxygen molecules is chemically adsorbed onto the clean noble metal surface where O=O molecule electron bonds are stretched leading to dissociation of the molecule into individual O atoms bonded to the precious metals surface. Carbon monoxide also diffuses from the main gas

stream and attracted to the same catalyst site. The carbon monoxide molecule and oxygen atoms react to form carbon dioxide, which desorbs from the surface and re-enter the gas stream. The movement of the oxygen, carbon monoxide inward from main stream to the catalyst sites and carbon monoxide outward to the main stream is governed by the laws of gaseous diffusion. The main driving force in this case is the concentration difference between each molecule in the main stream compared to the catalytic surface. The rate of reaction at the catalytic surface is highly dependent on the temperature at this surface.

1.3.2   NO REDUCTION CATALYST:

NO is removed by reduction using the CO, HC and H_2 in the exhaust. Reduction of NO can be carried out under rich conditions where there is an excess of reducing species. Use of rich mixture makes NO reduction catalyst work. Such a catalyst requires a follow-up oxidation catalyst, together with addition of air from an air pump before the oxidation catalyst, to remove the remaining CO and HC. NO reduction activity is in the order Ru>Rh>Pd>Pt.Ruthenium (Ru) and Rhodium (Rh) produce considerably less NH_3 than Pd or Pt under slightly rich conditions. As Ru is very volatile, Rh is used as the reduction catalysts.

1.3.3 THREE-WAY CATALYST:

If an engine is operated at all times with an air/fuel ratio at or close to stoichiometric air fuel ratio, then both NO reduction and CO and HC oxidation can be done in a single catalyst bed. This is called as three-way catalyst.

There is a narrow range of air/fuel ratios near stoichiometric in which very conversion efficiencies close to 90% for all the three pollutants are achieved.

Due to cyclic variation in exhaust gas composition about a set point close to stoichiometric A/F ratio and by use of promoters like CeO_2 the catalyst is able to reduce NO when a slight excess of O_2 in present (on the lean side) and remove CO and HC when there is slight deficiency of O_2 (on the rich side) Rhodium (Rh) is the principal ingredient used in catalyst to remove NO. It is very active for NO reduction.

1.4 CATALYST SUPPORT SYSTEMS:

1.4.1 PACKED BED REACTOR SYSTEM:

This converter design uses a bed of spherical ceramic pellets to provide a large surface area in contact with exhaust gas flow. With pellet catalyst support, the noble metal is impregnated into the highly porous surface of the spherical alumina pellets (typically 3 mm diameter) to a depth of about 250 μm .The pellet material chosen to have good crush and abrasion resistance after exposure to temperature of the order of 1000°C .The gas flow is turbulent which results in high mass transfer rates. The pelletized catalytic converters have a major disadvantage that they have high back pressure and power loss(Vora, K.C.,

Ghosh ARAI 1995). These losses would overcome through a combination of novel material development and

METAL MONOLITH
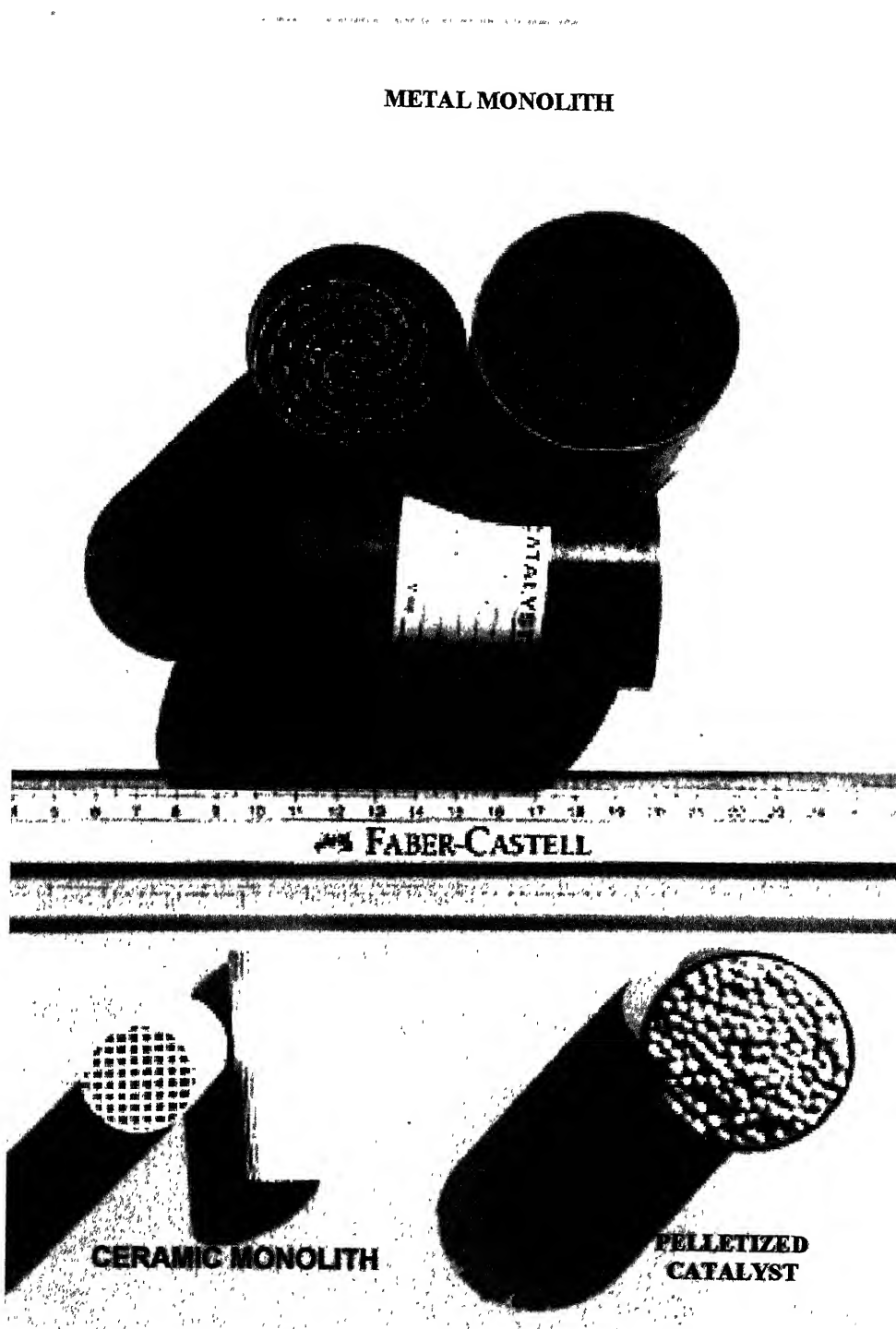
Fig: 1.4 Different Types of Catalysts Supports

Optimum design of catalytic reactor (D. Venkateshwaran, Sbhaduri, R. M. Cursel SIAT 96). They developed a converter having spherical beads, as catalytic carrier, that is characterized by its very low thermal expansion coefficient and better thermal shock and claimed that suitably canned and catalyzed this converter had unique advantage over conventional honeycomb catalyst on account of its high conversion efficiency, good durability and low cost.

Main Advantages and Disadvantages of the Pellet Converter in The Automotive Emission Control:

Advantages:

1. A uniform deposition of catalyst poisoning agents occurs over the converter, as the pellets move slowly around in the converter during us.

2. The exhaust gas flow in the pellet converter is turbulent, thus giving an enhanced gas to solid mass transfer rates.

3. Due to sudden changes in catalyst temperature, the risk of destroying the support by thermal shocks is very low

Disadvantages:

1. Attrition of particles and catalyst occurs in the bed;

2. Catalyst particles may be carried away in the exhaust gas stream;

3. Pressure drops per unit bed length is quite high.

1.4.2 MONOLITH REACTOR SYSTEM:

1.4.2.1 Ceramic Honeycomb Monolith:

The matrix of converter resembles a honeycomb structure consisting of thousands of parallel channels through which exhaust gas flows. This substrate honeycomb is made from a magnesium-aluminium silicate ceramic material, which withstands high working temperatures. These passage ways are covered with highly porous alumina (Al_2O_3) washcoat roughly 20μ thick which increases the effective surface area of the catalyst channels by a factor of roughly 700. This washcoat is impregnated by vapor deposition with the nobles metals Platinum (Pt) and Rhodium (Rh).

By 1972 (Tom Hinman, Symposium on International Automotive Technology, 99) Corning had invented the cellular ceramic substrate, which became the heart of the converter. During 1980's and 1990's ceramic substrate became a world standard used in 95% of all cars with converters. The first substrate had 200 cells per square inch, which further improved, to 300 cells per square inch by 1976 and now to almost 800 cells per square inch.

The honeycomb structure has approximately 1 mm square passageways with porous walls roughly 0.15 to 0.3 mm thick. There are about 30 to 60 passageways per square centimeter of frontal area. The washcoat covers a surface area of about 100 to 200 m^2/g and has a mass of about 5 to 15% of the honeycomb monolith.

Ceramic honeycomb structures are fragile and are mounted inside the casing of a highly alloy steel by using a special packing material. This protects the honeycomb from mechanical and thermal expansion stresses and external impacts, which may deform the outer casing.

1.4.2.2 Metallic Honeycomb (Monolith):

The metallic honeycomb substrate comprises thin steel foils of alternating layers of flat and corrugated foils of thickness ranging from 0.04 to 0.05 mm which are rolled over a width (corresponding to the specified length of the substrate) into a spiral or 'S'-shape configuration. Two separate honeycomb substrates are arranged end on in large converters with a small gap between them. This enables thorough mixing of the laminar flow in the second substrate, thus improving the pollutant conversion to harmless gases.

The metallic substrate is wound in a spiral or 'S' shape, as this provides a better distribution of the tension generated by thermal expansion so that both mechanical stability and life are increased. The contact zone between the flat and corrugated foil is subjected to special temperature soldering technique, which provides the support and rigidity necessary for the many hundreds of channel-ways. The metallic substrate coated with a highly porous alumina (Al_2O_3) washcoat which itself is very sparsely impregnated with the active noble metals Platinum (Pt) and Rhodium (Rh) .The metallic honeycomb structure is mounted inside a mantle, directly against the internal stainless-steel walls. This enables the effective frontal area of the substrate channels to be increased by about 15%

compared with ceramic honeycomb which has to be supported in a wire –mess or fiber mat to avoid the brittle damage. The significantly thinner metal walls and larger frontal area for the passage -ways for the similar-sized converter offers a much lower flow resistance to the exhaust gases.

This steel foil construction has a high mechanical durability and fatigue strength, with a relatively low exhaust –gas backpressure, and it can also absorb considerable outside deformation without causing serious damage to the substrate flow path. The disadvantages of the metallic honeycomb structure are that it is heavier than the ceramic honeycomb and is roughly 15% more expensive.

The Advantages of Metallic Substrates:

The metallic substrate can withstand for a short period, temperatures above 1300°C (including thermal shock), is durable, and show favorable starting/light-off behaviour than the ceramic monoliths. The metal quickly dissipates any localized heating.

The thin walls, approximately 0.04-mm thick, present minimal resistance to the exhaust gases,reducing back pressures.

The physical characteristics of metal allow more rapid attainment of necessary operating temperature. This serves to shorten the cold start phase and reduces pollutant emission. This is beneficial to the catalytic purification process by faster burn up of CO and HC coming from the engine under low temperature operation

such as at light loads, as well as under and urban and short distance driving conditions.

Metallic converter can be welded directly into the exhaust system, since the honeycomb is connected directly to a steel tube.

1.5   STATEMENT OF THE PROBLEM

In the present study our main aim is to reduce the emission value of exhaust gases for a small 4-stroke potable generator-set. The emission values of CO and HC are higher than the standards set by government of India for the year June 2001, for portable generators. In the present study we are using the catalytic converter to reduce the emission of portable generator-set. The following studies are proposed to be done.

1.   Study of emission characteristics of a 4-strok-kerosene generator set.

2.   Installation of monolith catalytic converter in the exhaust system of the test generator.

3.   Study of emission reduction with catalytic converter without and with secondary air injection.

CHAPTER 2

EXPERIMENTAL SET-UP AND METHODOLOGY

2.1: Objective of the Experiments:

The experiments were conducted with the purpose of knowing the performance of metal monolith catalytic converter on a four-stroke kerosene genset, using secondary air injection. In these experiment parameters to be measured are, CO, HC, CO_2, O_2, and Air – Fuel Ratio and Fuel Consumption, using gas analyzer and fuel consumption. The exhaust gas analysis is used to calculate air-fuel ratio shown by the analyzer itself.

2.2: Description of the Experimental Setup:

The experimental set up consists of following equipment's and instrumentations:

2.2.1 Test Engine coupled with an Electrical Generator

2.2.2 Reed valve

2.2.3 Exhaust Gas Analyzer

2.2.4 Pressure Measurement by a water manometer

2.2.5 Catalytic Converter Unit

2.2.6 Temperature Sensors for Exhaust Gas

2.2.6 Temperature Indicators

2.2.8 Blower

2.2.9 Electrical Power Absorption Unit

2.2.10 Rotameter for measurement of secondary air

2.2.11 Air box

2.2.12 Venturi for secondary air injection into exhaust pipe

2.2.1 Test Engine Coupled with an Electrical Generator:

The test engine used was a four-stroke petrol start kerosene run engine (Fig: 2.1). The technical specifications of the 4-stroke genset used in this study are given in the Table 2.1.

Table 2.1

S. NO.	Parameter	Specifications
1.	Engine Model	BIRLA-YAMAHA LG-700 K
2.	Engine Displacement	85 cc
3.	Type of Fuel	Kerosene
4.	Type of Engine	4-stroke SI engine
5.	Bore x Stroke	48 x 47 mm
6.	Rated Engine Speed	3000 RPM
7.	Rated Generator Output	1.08 hp
8.	Rated Voltage	220 V
9.	Compression ratio	5.1 : 1
10.	Rated Frequency	50 Hz
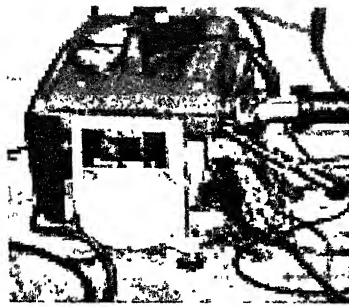
Fig : 2.1 Four Stroke Engine, Model LG 700 K

2.2.2 Reed valve:

The reed valve uses thin flapper petals. Reed petals are made of either fiber or flexible metal plates (Fig. 2.2). The reed petals are forced open as a pressure difference. This is the once through (one way)valve, prevents the flow of exhaust gases when fitted into the exhaust pipe of generator set and allows the air from the blower into the exhaust pipe.
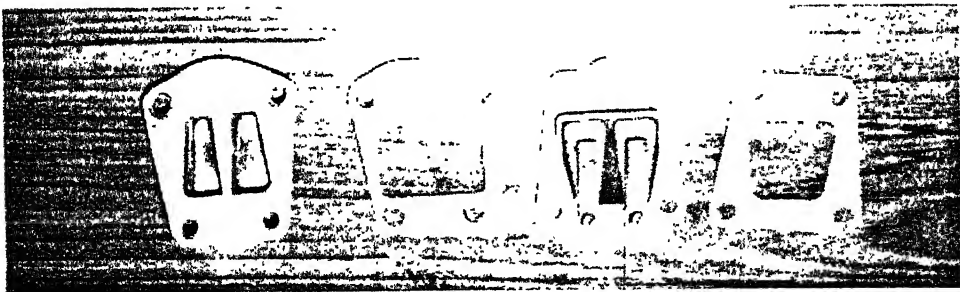
Fig: 2.2 Reed Valve
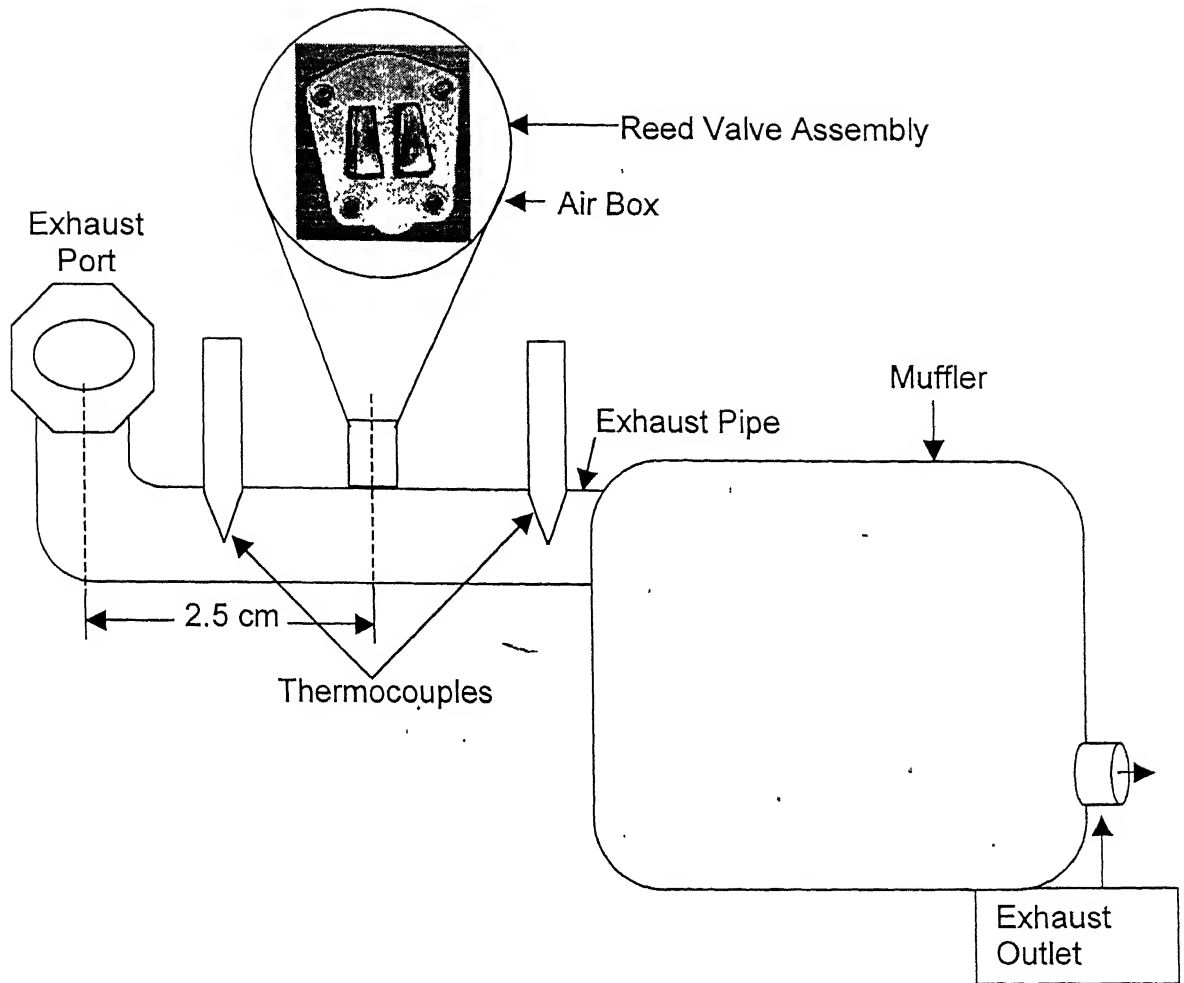
Fig: 2.3   Reed Valve Assembly fitted in Exhaust Pipe.

2.2.3 Exhaust Gas Analyzer (Emissions measurement):

Automotive emission analyzer MEXA – 554 JA (Fig: 2.4), manufactured by M/s HORIBA Limited, Kyoto, Japan, was used to measure engine exhaust gas concentration of Carbon monoxide, hydrocarbons, carbon dioxide, oxygen and displayed the Air/Fuel ratio calculated from exhaust gas composition . Online measurement were displayed, on LCD display panel as parts per million (ppm) by volume of HC and %vol, concentration for rest of the species.
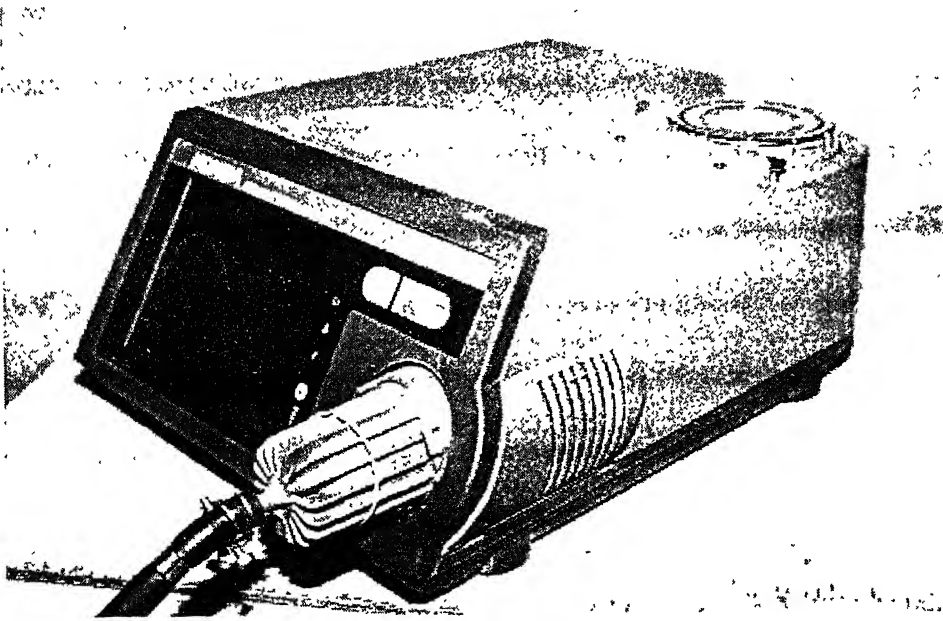
Fig: 2.4   Exhaust Gas Analyzer

This analyzer works on the principle of Non–Dispersive-Infra-Red (NDIR) technique, i.e. the absorption of infrared radiations by the gas to be analyzed."Non- Dispersive" refers to the fact that the infrared radiations are not resolved into discrete spectral levels but, instead, involves absorption of distinctive wavelength regions within the infrared range [Spriger and Patterson,

1973]. While CO, CO_2 and HC were detected by this method, O_2 was detected by the use of a polarographic detector, an Electro-chemical device.

The sampling circuit consisted of sampling tube of 1.5 m length, a pre-filter element and the sampling probe attached at one end and the water separator at the other end.

This sampling line assembly is fitted to the gas analyzer at the gas inlet. The sample is drawn by an in-built suction pump in the analyzer. It is ensured that all the associated filter units are cleaned before measurements.

The unit was calibrated using standard calibration gas bottle supplied by the analyzer manufactures. The span calibration of O_2 was automatically performed when zero calibration of other gases was carried out using clean air, and zero calibration of O_2 was performed when the span calibration of other gases is carried out. The calibration was done as and when indicated by the control display unit as per the prescribed procedure. Before starting the measurements, the unit was started in the "warm-up" mode for a specified time of 5 minutes. Then, two tests were carried out i.e. (a) HC hang –up test- to ensure that the sampling circuit is free from any residual HC, and (b) Leak test – to ensure that the sampling circuit was leak proof. After these tests, the standard measurement procedures and precautions, as described in the Instruction manual were followed.

2.2.4. Pressure Measurement by a water manometer:

Water U-tube manometer; with normal visual level recording was used to measure the pressure drop across the reed valve and venturi.

2.2.5 Catalytic converter:

Monolith Converter:

The Metal Monolith Converter used was DEGUSSA CATALYST SAMPLE (Fig.2.5) having following specifications.

CODE	:	181
Diameter	:	33 mm
Length	:	60
Standard ID	:	E5521628
CPSI	:	100
Substrate Make	:	EMITEC
NM/Tech	:	D/HOSC
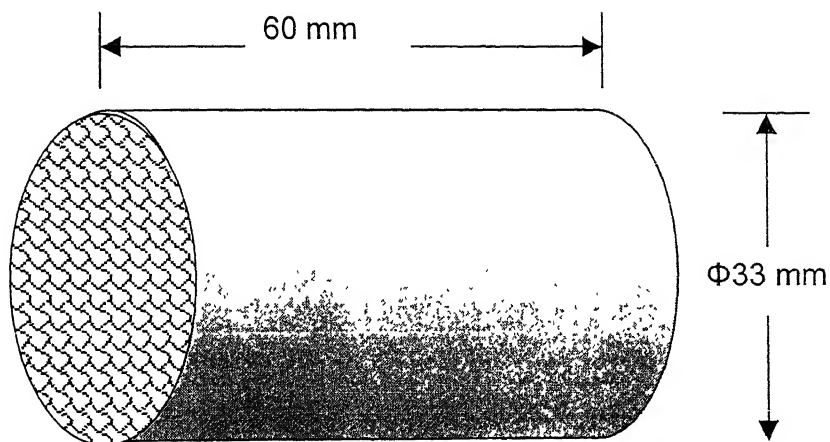
Fig: 2.5   Metal Monolith Converter with S-Shape Design
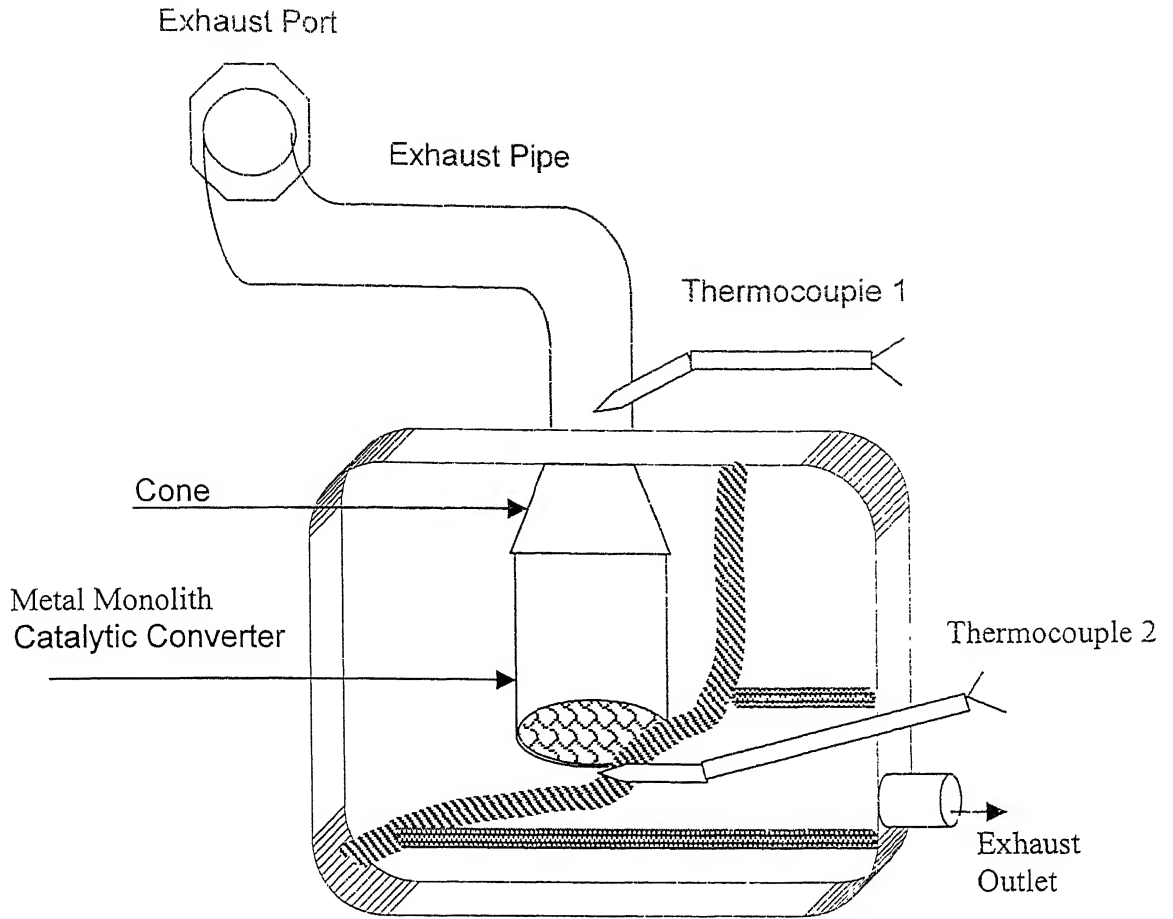
Fig: 2.6   Schematic Diagram Showing Catalytic Converter and
            Thermocouple inside the Muffler
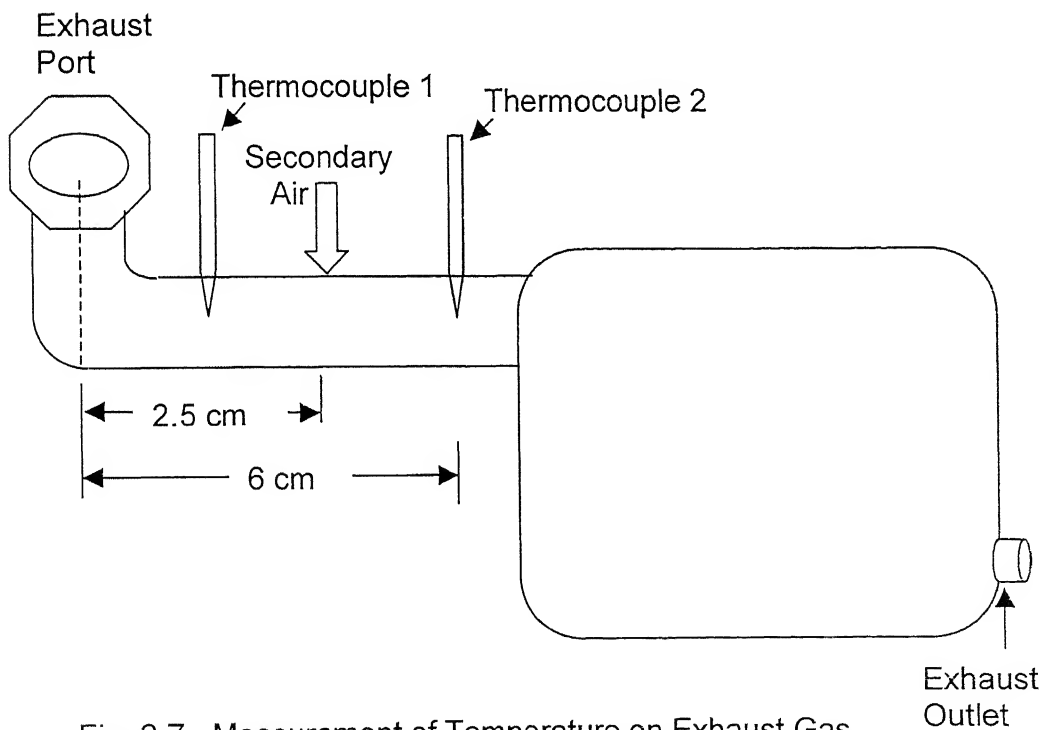
Fig: 2.7   Measurement of Temperature on Exhaust Gas

Temperature measurement:

Two holes were drilled, one just before the catalytic converter and second just after the converter in the exhaust pipe and muffler, respectively. Arrangement was made to securely fit two thermocouples, with the ceramic insulator supports of 5-mm diameter into these holes, as shown in the Fig: 2.6, temperature also measured before and after the point of secondary air injection as shown in the Fig: 2.7.

2.2.6 Temperature Sensors for Exhaust Gas:

Stainless steel braided Cr/Al thermocouple of 0.4 mm Φ, range $0°C - 900°C$, with added fiberglass insulation, were used to measure the temperature. No separate compensating cable was used as the thermocouple wire itself was directly connected to the indicator input .To protect the thermocouples, ceramic beads of outer diameter 5 mm were used .The couples had overall accuracy of $\pm 0.5\%$ of the working range.

2.2.7 Temperature Indicator:

Temperature indicators manufactured by M/s Blue Bell Limited, Kanpur, India, capable of measuring temperature from six independent channels, were used. It had a 4 digit, 18mm x 12mm, LCD display unit. The front panel had a 6-point selector switch, which could be pressed to indicate the temperature of the respective channels. Only one temperature value was displayed at a time. The

unit worked on universal I/O mode with 240 AC ±10% @ 50 Hz and having an overall accuracy of ±0.5% over the safe working range of the instrument.

2.2.8 Blower:

Four stroke kerosene genset runs at rich mixture (approximately 10.5: 1 AFR) for smooth running. This lead to high emissions of CO and unburned HC in the engine exhaust, To oxidize CO and HC in the converter, sufficient oxygen is required. So the extra oxygen is to be supplied in the form of secondary air with the help of a blower or any other air induction system. In this study, a blower manufactured by Kulkarni Power Tools Pvt. Ltd. with the following specifications was used.

Rated Voltage   :   240V

Rated Current   :   1.6 amp

Power   :   350W

Volumetric Discharge   :   1710 lit/min

2.2.9 Electrical Power Absorption Unit:

To generate data at different test engine operating conditions, the generator output was fed to an electrical power absorption unit. This unit was fabricated as shown in Fig: 2.11 The panel of the unit was fitted with 'ON/OFF' switches operating an array of standard incandescent lamps of various power ratings from 25W to 200W.

These lamps were installed at the rear part of the unit. It was possible to load the

generator through its complete operating range from 0-780 VA. Analog indicators measured the generator voltage and the current drawn by the circuit. The electrical power absorption unit was fabricated with wooden framework and the paneling provided by 8-mm standard ply-board. The unit was lightweight, compact and portable

2.2.10   Rotameter for Measurement of Secondary Air:

A rotameter consists of a vertical tube tapered bore in which a "float" (spherical shape) assumes a vertical position corresponding to each flow rate through the tube (Fig: 2.8) and used to measure the fluid flow rate. For a given flow rate, the float remains stationary since the vertical force of differential pressure, gravity viscosity, and buoyancy are balanced. In this study, a rotameter manufactured by Instrumentation Engineers Pvt. Ltd. with the following specifications was used.

Fluid   `   :   Air

Density   :   1.165, Kg/m^3

Viscosity   : $1.86*10^{-5}$, N sec/m^2

Temperature   :   30°C

Pressure   :   Atmospheric

Direction of flow   :   Rear

Scale   :   Litre/sec.

Model No.   :   11140
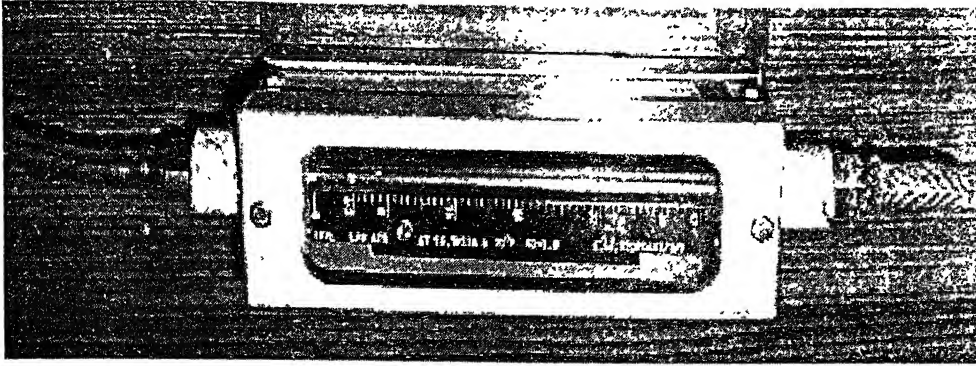
Fig: 2.8 Rotameter

2.2.11   Air Box:

To inject the secondary air through reed valve, fitted into an air box. The air box and reed valve into it are shown in Fig: 2.3.

2.2.12   Venturi For Secondary Air Injection Into Exhaust Pipe:

A venturi with dimensions (Fig: 2.9) was used to develop pressure drop at the throat to induce suction of air into the exhaust pipe. A hole is drilled at the throat for secondary air injection and both the converging and diverging ends were connected to the exhaust pipe. It was made of mild steel.
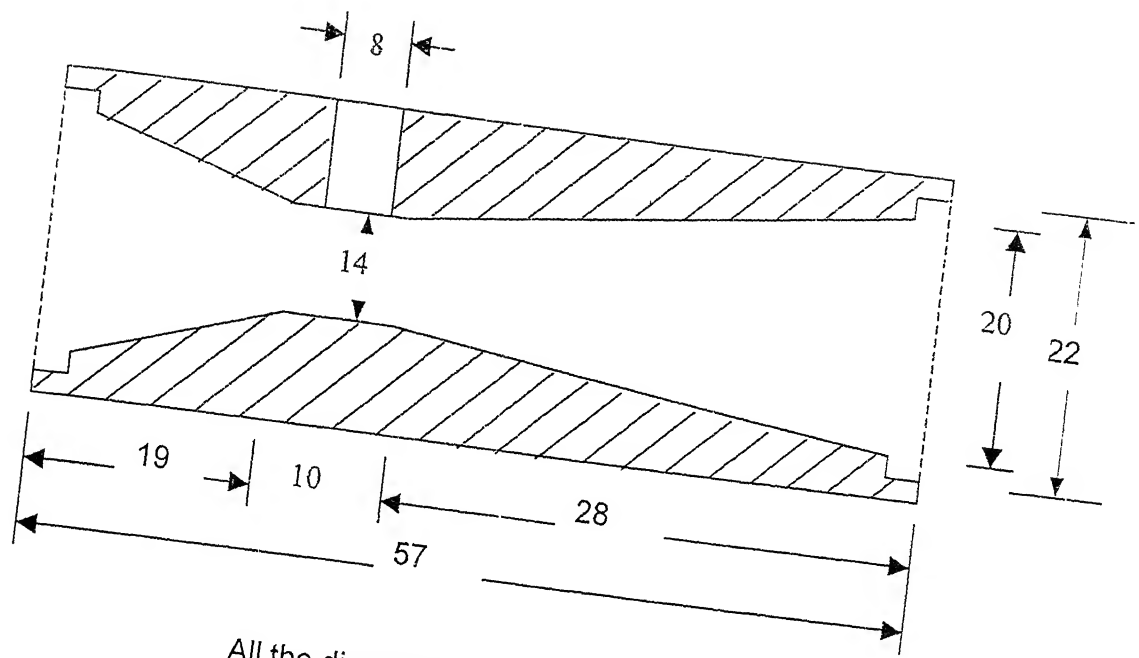
All the dimensions are in mm.

Fig : 2.9   Longitudinal Cross Section of Venturi
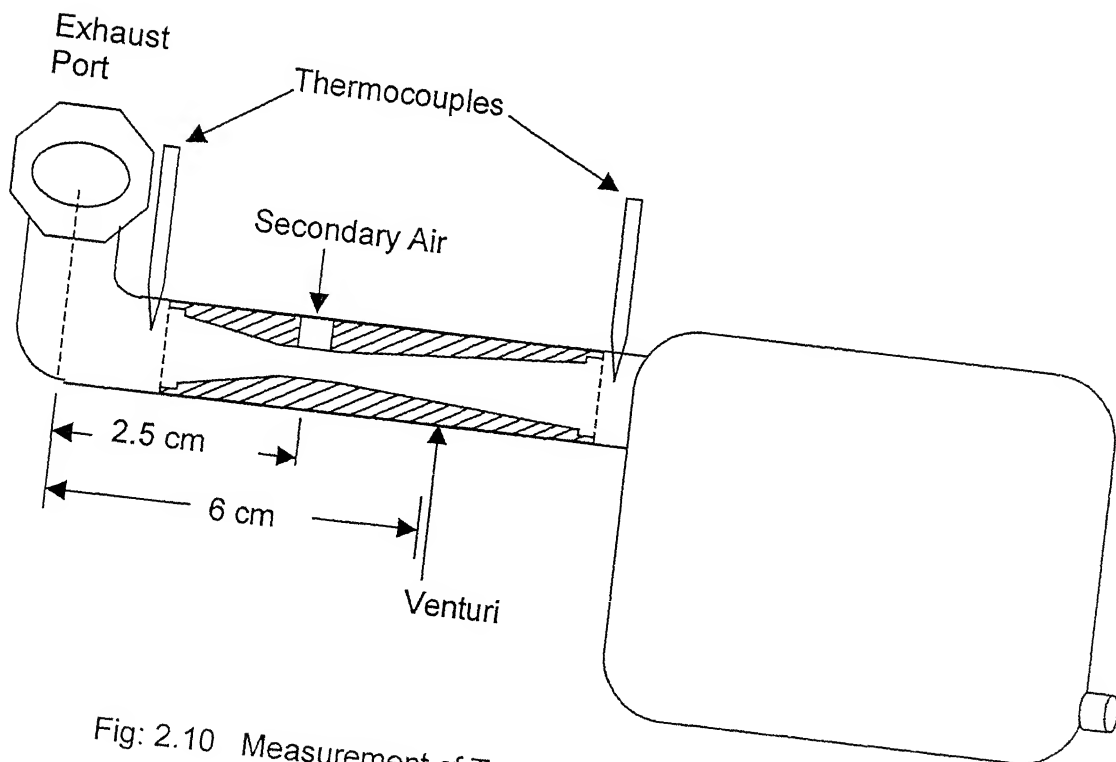
Fig: 2.10   Measurement of Temperature on Exhaust Gas

2.3   Experimental Methodology:

The complete experimental set-up is shown schematically in Fig: 2.11. A typical experiment run was carried out as per the following procedures:

1. Before starting each test run, the exhaust gas analyzer was started in the warm-up mode and there after the calibration was done as per prescribed methodology in the manufacturer's instruction manual. Then, HC hang-up test and leak test was carried out to ensure that there is no residual HC in the sampling circuit and that the circuit is free from any leaks.

2. The engine was started and after the initial warm-up period, it was loaded as required. Then, the engine was operated for approximately 10 – 15 minutes to attain steady state condition. The objective was to stabilize all the engine parameters that affect emissions prior to start of any emissions measurements. The criterion for thermal stability was to stable engine out exhaust gas temperature and sufficiently stable engine out emissions level. These two parameters were continuously monitored and final data recording was started only after thermal stability was ensured.

3. The U tube manometer was connected through PVC tubing with leak proof brass connectors to the throat of venturi fitted in exhaust pipe at a distance of 2.5 cm. from the exhaust port. The pressure drop across the atmosphere and inner side of pipe was recorded.

4. The gas temperature was recorded by putting the thermocouples at the required points in the exhaust system. The ambient temperature temperature was also recorded through a separate thermocouple.

5. The similar procedure was carried out for measuring the data at different loads.

6. For measurements with secondary air after the engine stabilization the secondary air was inducted into the exhaust stream of the engine, in upstream side of the converter.
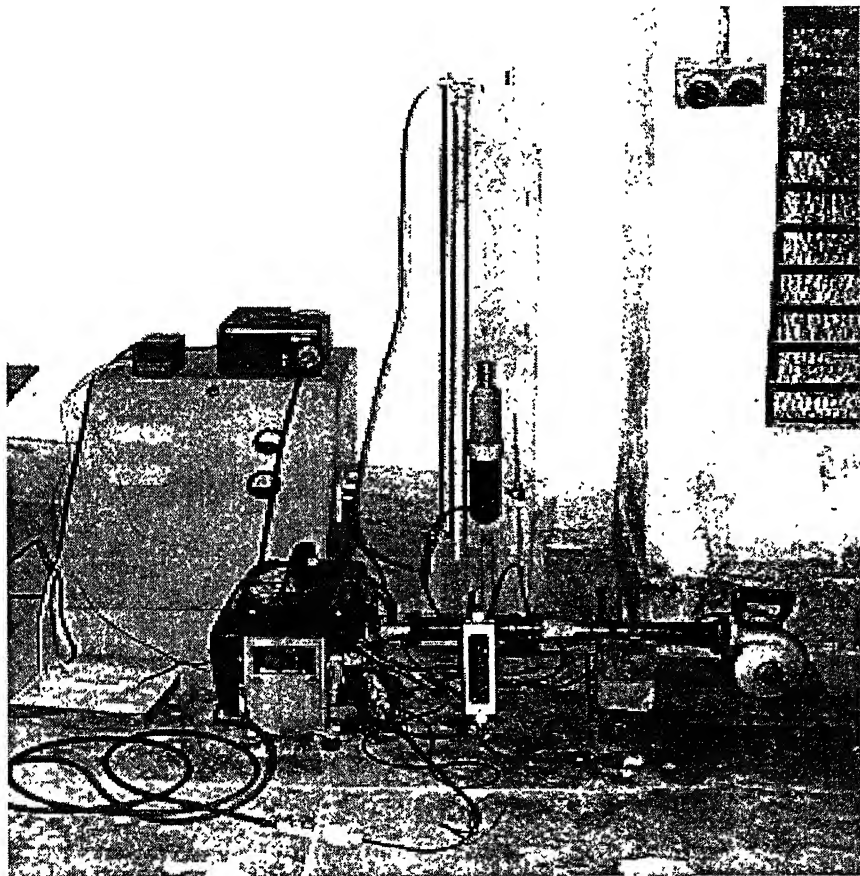
Fig: 2.11 Experimental Set-up

2.4 Experimental Uncertainties:

Errors in the experiment may arise due to various reasons. These can be classified as:

(a)   Systematic or determinate errors, arising as a result of faults in the equipment or poor calibration of instruments.

(b)   Random or unavoidable errors, arising as a result of uncertainty associated, the accuracy of measuring instrument and the ability to read such instruments both accurately and consistently.

(c)   Errors in pumping the secondary air, quantity of secondary air may vary during test even at the same test condition due to changes in engine operation.

(d)   Calculated air–fuel ratio depends on the exhaust gas composition and error in measurement of exhaust gas composition will be reflected in the value of A/F. Large variations from actual air-fuel ratio may result at higher concentrations of HC as the composition of later is not known correctly. While no attempt has been done in the present study to quantity these errors, all feasible efforts within the practical limits have been implemented to ensure that the possible errors are minimized.

(e)   In a classical sense, it was not possible to repeat precisely identical experiments, mainly due to variations in the inherent combustion characteristics of the engine' and ambient temperatures etc. Instead the approach adopted was to perform the experiment under nearly identical

conditions. The data acquired thus was compared and satisfactory level of repeatability was observed.

CHAPTER 3

CALCULATION OF MASS EMISSIONS

In the present study the observed data measured with the help of gas analyzer are in % volume for CO, CO_2, and O_2 and for HC in ppm. To calculate emission rate of CO and HC in g/hr the following methods was used.

3.1 Conversion of molar concentration in dry exhaust to wet exhaust

Species concentration, wet = K * species concentration, dry

Where:

$$k = \frac{1.0}{1 + 0.005 * (CO\%_d + CO_2\%_d) * y - 0.01 * H_2\%_d}$$

$$H_2\%_d = \frac{0.5 * y * CO\%_d * (CO\%_d + CO_2\%_d)}{CO\%_d + 3 * CO_2\%_2}$$

Y = H/C Atomic ratio of test fuel
 = 2.0 for kerosene fuel

3.2 Carbon balance method:

$$W_{co} = \frac{M_{co}}{MF} * \frac{G_F}{TC} * CO\%, w$$

3.3 Conversion of molar concentration of species to mass emission in g/hr

$$W_{HC} = \frac{M_{HC,exh}}{MF} * \frac{G_F}{TC} * \frac{HC, ppm, w}{10000}$$

Where:

G_F = Mass flow rate of fuel in g/hr

W_{CO} = Mass emission rate of CO in exhaust in g/hr

W_{HC} = Mass emission rate of HC in exhaust in g/hr

TC = CO%wet + CO2%wet+ HC%wet

$M_{HC, exh}$ = MF (this assumes that the exhaust gas hydrocarbons are

identical to Unburned fuel)

MF =Molecular weight of fuel per carbon

=12.011+1.008*y+15.999*z

M_{co} = Molecular weight of CO = 28.01

Y = H/C atomic ratio of the fuel

Z = O/C atomic ratio of the fuel*

- For kerosene the Z value is 'zero'
- Density of kerosene fuel = 790 Kg/m^3

3.4 Conversion Efficiency:

(Mass emission value at inlet to the converter)-(Mass emission value at outlet to the converter) / (Mass emission value at inlet to the converter)

CHAPTER 4

RESULTS AND DISCUSSIONS

Test results obtained on 4-stroke kerosene genset, Model LG 700 K, and are discussed below.

4.1 Performance of catalytic converter without secondary air

Test results obtained on the test 4-stroke kerosene genset, Model LG 700K, are discussed below.

At first, the performance and emission of genset engine were determined without secondary air.

Test data obtained on exhaust gas composition at inlet and outlet, of the catalytic converter, the calculated air fuel ratio in the converter observed at different generator output are given in Table 4.1 and Table 4.2.The concentration of CO, HC, CO_2 and O_2 at inlet and outlet of the converter at different genset output are shown in Figs: 4.1 and 4.2, respectively.

The air fuel ratio (AFR) is determined by the exhaust gas analyzer MEXA – 554 JA (Fig: 2.4) from the measured CO, CO_2 HC and O_2 concentrations. The air fuel ratio is seen in the range between 10 to 10.9 compared to the stoichiometric air fuel ratio equal to 14.7. The variation of air fuel ratio shown in the Fig: 4.3. The calculated AFR at inlet and outlet are very close showing the acceptable accuracy of measurements.

Results show that the engine operates very rich and there is deficiency in oxygen availability for catalytic oxidation of CO and HC.

The mass emission of CO and HC were calculated from their measured from exhaust gas concentrations, measured fuel flow rate and calculated air fuel ratio. Details of calculations are given the Appendix. Mass emission of CO and HC are given in the Table 4.3 and variation of mass emission of CO and HC are shown in the Fig 4.4 and Fig 4.5.

CO emissions ranged from 268.2 g/hr to 385g/hr, without converter and 232.3 g/hr to 268.5 g/hr with converter. Mass emissions of HC ranged from 0.73 g/hr to 0.82 g/hr without converter and 0.68 g/hr to 0.79 g/hr with converter.

It is seen that there is a small conversion in CO and HC. As very little free oxygen in the exhaust gas is present to oxidize CO and HC, very small reduction in CO and HC is observed. Variation of catalytic conversion efficiency is given in the Fig 4.6. Conversion efficiency is very low, in the range of 3.8% to 13.3% for CO and 2.5% to 10.8% for HC.

Exhaust gas temperature Table 4.2 at the converter outlet are lower than than the inlet. This is caused due to cooling of the exhaust gases and due to fact that hardly any energy is released due to very little oxidation of HC and CO.

4.2   Performance with Secondary Air

From the preceding study it is clear that to make the catalytic converter effective, either engine has to be operated lean or secondary air has to be introduced upstream of the converter. For stable operation of kerosene fuelled, SI engines rich mixtures have to be used. Hence, it was decided to introduce secondary air in the exhaust system. For optimum conversion, amount of secondary air has to be suitably controlled at different engine outputs. For this, necessary hardware has to be designed.

4.2.1   Systems for Secondary Air Introduction

1.   In the present study first attempt was made to inject the secondary air upstream of converter by placing reed valve assembly (Fig: 2.3) in the exhaust pipe in the upstream of the converter. The tests were done and observed data are given in Table 4.4. It is seen again that very small reduction in CO and HC are observed

2.   Second attempt was made to inject secondary air upstream of converter by placing a venturi assembly (Fig: 2.10) in the exhaust pipe.

As very small quantity of secondary air is presumably injected even with venturi designed for 250 mm H_2O. The vacuum measured at the throat of venturi is shown in the Table: 4.5 for different genset outputs. The vacuum is very low and varied from 3.8 to 6.4 mm of H_2O. This is attributed to the high back pressure caused by fitment of venturi and catalytic converter resulting in a small vacuum with respect to atmosphere.

The emission tests were carried out and the observed data are given in Table 4.6. Again very small reductions in CO and HC are observed.

As the secondary air is introduced, there will be the dilution of the exhaust gas resulting in reduction in the observed CO and HC concentration even at the inlet of the converter. Therefore, to evaluate efficiency of converter, mass of emission data in terms of g/hr have been calculated and used.

Mass emission of CO and HC for without secondary air, with secondary air through reed valve, with venturi is compared given in the Table 4.7 for CO and Table 4.8 for HC emissions. The data are further compared in Fig: 4.7 and Fig: 4.8 for CO and HC, respectively. The results show only marginal increase in CO and HC conversion with reed valve and venturi for secondary air injection.

4.2.2 Secondary air injection by a blower:

In the final attempt, a blower was used to introduce the secondary air upstream of catalytic converters the blower available was of a high capacity, excess air was by-passed. The amount of secondary air introduced was varied and measured by rotameter. The arrangement of secondary air injection is shown schematically in Fig: 2.11.

4.2.3 Effect of Secondary Air Flow Rate on Conversion:

First, at 300W and 600W outputs, secondary air injection was studied in a wide range to determine optimum amount of secondary air. The emission tests were carried out and the observed data are given in Table 4.9 to Table 4.10 and mass emission of CO and HC, conversion efficiency of CO and HC are given Table 4.11 and data are compared in the Fig: 4.9 to 4.11 for 300W output. For 600W

output the observed data are given in table 4.12 and table 4.13 and mass emission of CO and HC, conversion efficiency of CO an HC are given Table 4.14 the data are compared are in the Fig 4.12 to 4.14. It is seen that 300W output, with increase in secondary air injection, at first CO and HC reduce. However, after a certain amount of secondary air injection. CO and HC start increasing again. For example at 300W load, when secondary is increased beyond 0.376 l/s, both CO and HC increased (Fig: 4.9). It was observed that the exhaust gas temperature at the converter inlet drops below 282°C (Table 4.10 and Fig: 4.11) when secondary air was increased above 0.376 l/s , then CO HC oxidation started falling. At secondary air inject in equal to 0.406 l/sec, the exhaust gas temperature at catalytic converter inlet was 250°C below which catalytic converter falls rapidly. At 600W output, exhaust gas temperature remain quite high (410°C) even at the maximum secondary air rate used(0.546 l/sec) and CO and HC show continuous reduction even upto 0.546 l/sec secondary air injection (Fig: 4.12).

At 300W, maximum CO conversion efficiency close to 89% was observed while maximum HC conversion efficiency of 37% was observed. On the other hand for 600W output, maximum CO conversion efficiency was nearly 95% and for HC about 55%.

4.2.4 Catalytic Converter Performance at Different Genset Outputs:

The observed performance and emission data with different amount of secondary air at different genset output are given in Table 4.15.

Mass emission data with different amount of secondary air and maximum conversion efficiency for CO and HC observed at different loads are given in the table 4.16. Mass emissions of CO range from 213 g/hr to 332 g/hr and HC from 0.45 g/hr to 0.65 g/hr at the inlet to the converter, At the converter outlet CO range from 14.8 g/hr to 156.4 g/hr and 0.28 g/hr to 0.44 g/hr at different loads. The conversion of CO and HC at different loads is shown in the figures 4.16 to 4.29. From theses data maximum conversion efficiency was determined at

different loads for CO and HC, given in the Table 4.16. The variation of maximum CO and HC conversion efficiency are shown in the Fig 4.30. The maximum conversion efficiency of CO is 93.42% and HC is 56.38%.

4.2.4 Theoretical and Measured Flow Rates of Secondary Air for maximum Conversion

Stoichiometric requirement of secondary air for complete conversion of CO and HC at different generator output is given in Table 4.17 and shown in Fig 4.15. The measured amount of secondary air for different generator output and corresponding CO and HC emissions is given in the Table 4.17 and performance with a wider range of secondary air studied for 300W and 600W outputs in the Tables 4.9 and 4.12, respectively. The measured secondary air for maximum conversion observed for CO and HC is compared with the stoichiometric requirement of secondary air in Fig 4.15. The requirement of secondary air is increasing with output, as the fuel flow rate is increases with the genset output. It is seen that the theoretically estimated stoichiometric requirement of secondary air compares well with the measured values.

For example, at load of 300W, actual secondary air requirement for maximum conversion of CO and HC is 0.376 l/sec while stoichiometric secondary air requirement is 0.336 l/sec, but at loads of 600W, the actual secondary air requirement is 0.546 l/sec while stoichiometric secondary air requirement is 0.434 l/sec for maximum of CO and HC.

Table 4.1

Performance Test Data with Metal Monolith Catalytic Converter on Four-Stroke Kerosene Gensets, LG 700K Model, without Secondary Air Injection

Ambient Temperature = 24°C

Load Watts	CO, %vol		CO₂, %vol		O₂, %vol		HC, ppm		AFR		Fuel Flow Rate (Sec)
	In	Out	In	Out	In	Out	In	Out	In	Out	
Idle	9.46	8.40	8.45	9.96	2.36	0.78	550	540	10.6	10.1	223
100	9.50	8.50	9.70	10.2	1.90	0.44	540	525	10.8	10.0	208
200	9.45	8.80	9.80	10.3	1.40	0.34	483	462	10.3	10.1	195
300	10.03	9.54	9.36	9.64	0.68	0.32	466	440	10.0	10.1	166
400	10.1	9.33	9.50	9.50	0.67	0.28	435	414	10.9	10.5	155
500	9.93	9.1	10.1	10.1	0.34	0.24	389	360	10.1	10.2	149
600	9.50	9.0	10.2	10.5	0.26	0.22	368	322	10.5	10.2	142

Table 4.2

Measured Temperature in Converter on Four-Stroke Kerosene Gensets, LG 700K Model, without Secondary Air Injection, Ambient Temperature = 24 °C

T_1= Temperature at inlet to converter
T_2= Temperature at outlet to converter

Load (Watts)	Temperature T_1°C	Temp. T_2°C
Idle	498	392
100	503	408
200	508	423
300	511	443
400	521	454
500	550	473
600	551	491

Table 4.3

Mass Emission Rate and Conversion Efficiencies Converter, without Secondary Air, keeping Converter inside the Muffler

Load, Watts	CO, g/hr		Conv.Eff. CO	HC, g/hr		Conv.Eff. HC
	Inlet	Outlet		Inlet	Outlet	
Idle	268.2	232.34	13.3	0.78	0.74	5.1
100	269.4	247.5	8.1	0.77	0.75	2.6
200	285.2	267.7	6.1	0.73	0.70	4.1

300	353.1	339.5	3.8	0.82	0.78	4.8
400	376.1	358.2	4.7	0.81	0.79	2.5
500	377.2	356.9	5.4	0.73	0.70	4.1
600	385	368.5	4.3	0.74	0.66	10.8

Table 4.4

Performance Test Data of Kerosene Genset, LG 700K Model, with Reed Valve Assembly for Secondary Air Injection, Ambient Temperature = 30°C

T_1 = Temperature before to point of secondary air injection
T_2 = Temperature after point of secondary air injection

Load, Watts	CO, %vol	CO_2, %vol	O_2, %vol	HC, Ppm	Temp. T_1 (°C)	Temp. T_2 (°C)	Fuel flow rate (Sec)
Idle	8.96	8.48	2.80	437	582	437	242
100	9.22	8.66	2.40	353	575	443	206
200	9.32	8.88	2.06	346	575	451	193
300	9.25	8.90	1.88	307	578	454	165
400	8.70	9.46	1.66	352	584	461	154
500	8.21	9.84	1.54	319	593	470	147
600	8.86	9.64	1.34	305	593	474	142

Table 4.5

Pressure drop across the venturi
Ambient Temperature = 29°C

Load	ΔP mm of H2O
Idle	6.4
100	6.4
200	5.1
300	5.1
400	5.1
500	3.8
600	3.8

Table 4.6

Performance and Emission Data with Catalytic Converter on Kerosene Genset, LG 700K Model, with Secondary Air using Venturi ,
Ambient Temperature = 28° C

$T_1=$ Temperature before to point of secondary air injection
$T_2=$ Temperature after point of secondary air injection

Load Watts	CO, %vol	CO_2, %vol	O_2, %vol	HC, ppm	Temp. T_1 (°C)	Temp. T_2 (°C)	Fuel flow rate (Sec)
Idle	7.59	10.54	1.24	572	552	434	223
100	8.83	9.332	0.94	445	564	441	208

200	8.95	10.12	0.60	459	571	449	195
300	10.17	9.72	0.40	453	580	456	166
400	9.86	10.02	0.24	430	587	463	155
500	9.43	10.42	0.20	396	594	470	148
600	9.12	10.58	0.16	384	596	478	142

Table 4.7

CO Mass Emission Rate with different Air Injection Methods

Load, Watts	CO, g/hr	Without SAI,CO, g/hr	With Reed Valve, CO, g/hr	With Venturi, CO, g/hr
	Inlet	Outlet	Outlet	Outlet
Idle	268.2	232.34	240.5	212.6
100	269.4	247.5	283.8	264.8
200	285.2	267.7	300.8	272.7
300	353.1	339.5	350.2	349.1
400	376.1	358.2	352.6	262.6
500	377.2	356.9	350.8	363.8
600	385.0	368.5	382.4	369.6

Table 4.8

HC Mass Emission Rate with different Air Injection Methods

Load, Watts	HC, g/hr	Without SAI, HC, g/hr	With Reed Valve, HC, g/hr	With Venturi, HC, g/hr
	Inlet	Outlet	Outlet	Outlet
Idle	0.78	0.74	0.68	0.80
100	0.77	0.75	0.64	0.67
200	0.73	0.70	0.66	0.70
300	0.82	0.78	0.71	0.77
400	0.81	0.79	0.70	0.79
500	0.73	0.68	0.68	0.77
600	0.74	0.65	0.65	0.77

Table 4.9

Performance and emission Data with e Kerosene Gensets, LG 700K Model, with secondary air injection at load 300W, Ambient Temperature = 24°C

Air Flow Rate, L/Sec	CO, ,% Vol		CO_2, ,% Vol		O_2, ,% Vol		HC,ppm	
	in	out	in	out	in	out	in	out
0.226	5.70	3.53	7.85	13.89	5.78	1.23	214	181
0.240	5.64	2.60	7.75	12.2	6.20	1.60	211	162
0.263	5.41	1.86	7.42	11.56	6.85	2.15	202	159
0.293	4.45	0.96	6.10	9.30	9.00	3.55	168	135

0.320	3.86	0.48	5.30	6.34	10.50	6.30	145	91
0.333	2.82	0.32	3.87	5.14	13.50	10.92	105	89
0.346	2.42	0.29	3.32	5.00	14.46	13.44	90	81
0.376	1.62	0.22	2.22	4.50	16.60	15.75	61	71
0.390	1.57	0.23	2.10	3.98	16.79	15.98	57	72
0.406	1.50	0.48	1.99	3.41	16.90	16.87	54	73
0.546	1.40	0.79	1.92	3.45	17.06	18.14	53	76

Table 4.10

**Measured Temperature in Converter on Genset, LG 700K Model, with
Secondary Air Injection at Load 300W
Ambient Temperature = 24°C**

Air Flow Rate, Litre/Sec.	Temp., In (°C)	Temp., Out (°C)
0.226	428	557
0.240	418	546
0.263	401	539
0.293	372	526
0.320	346	524
0.333	326	521
0.346	313	518
0.376	282	513
0.390	266	508
0.406	250	498
0.546	178	473

Table 4.11

Mass emission rate of CO and HC in monolith converter, with different air injection methods, keeping converter inside the muffler

Air Flow Rate, Litre/Sec.	CO, g/hr		HC, g/hr		Conversion Eff.	
	In	Out	In	Out	CO	HC
0.226	284.0	136.8	0.53	0.41	51.81	22.96
0.240	284.3	118.6	0.53	0.39	58.27	25.02
0.263	284.6	93.5	0.53	0.38	67.11	27.88
0.293	284.7	63.2	0.53	0.37	77.81	30.92
0.320	284.4	47.5	0.53	0.36	83.29	32.72
0.333	284.5	39.5	0.53	0.35	86.29	32.65
0.346	284.5	37.0	0.53	0.35	86.99	33.64
0.376	284.7	31.4	0.53	0.33	88.95	36.93
0.390	284.5	36.8	0.53	0.39	87.04	24.98
0.406	284.5	83.3	0.53	0.40	70.73	23.67
0.546	284.6	125.7	0.53	0.42	55.82	21.61

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Table 4.12

Performance Test Data with Converter on Genset, LG 700K Model, with Secondary Air Injection at Load 600W, Ambient Temperature = 24 °C

Air Flow Rate, L/Sec.	CO, %vol.		CO2, %vol.		O2, %vol.		HC,ppm	
	In	Out	In	Out	In	Out	In	Out
0.286	4.58	3.17	8.59	12.5	6.15	0.37	177	150
0.313	4	2.16	7.51	12.7	7.5	1.2	156	135
0.323	3.62	2	6.81	12.9	8.6	2.25	140	124
0.336	3.27	1.4	6.14	13	9.25	3.9	126	112
0.390	3	0.86	5.64	13.1	10.4	8.7	116	103
0.420	2.6	0.47	4.87	12.5	12.2	10.3	100	91
0.546	1.8	0.23	3.37	12	15.78	16	70	75

Table 4.13

Measured Temperature in Converter on Genset, LG 700K Model, with Secondary Air Injection at Load 600W. Ambient Temperature = 24 °C

Air Flow Rate, L/Sec.	T_1 (°C)	T_2 (°C)
0.286	460	572
0.313	445	560
0.323	439	551
0.336	436	545
0.390	428	535
0.420	423	525
0.546	410	508

Table 4.14

Mass emission rate of CO and HC and conversion efficiency in converter, with different air injection methods, at load 600W

Air Flow Rate, L/Sec.	CO, g/hr		HC, g/hr		Conversion Eff.	
	In	Out	In	Out	CO	HC
0.286	270.2	157.2	0.52	0.37	41.80	28.74
0.313	270.0	112.9	0.52	0.35	58.15	32.94
0.323	269.6	104.3	0.52	0.32	61.30	37.96
0.336	270.0	75.5	0.52	0.30	72.00	41.88
0.390	269.7	47.9	0.52	0.28	82.24	45.01
0.420	270.4	28.2	0.52	0.27	80.58	47.55
0.546	270.4	14.6	0.52	0.24	94.59	54.67

Table 4.15

Performance and Emission Data with Converter on LG 700K Model Genset, with Secondary Air Injection by Blower, Ambient Temperature 25 °C

Load Watts	Air Flow Rate L/Sec	CO, %vol		CO_2, %vol		O_2, %vol		HC, Ppm		Fuel flow rate (Sec)
		in	out	in	out	in	out	in	out	
Idle	0.187	6.55	3.70	8.0	13.66	4.26	1.8	377	306	226
	0.200	5.70	1.80	6.90	15.54	6.00	2.34	328	284	
	0.226	5.40	0.50	6.59	14.00	7.20	2.56	311	226	
	0.260	4.90	0.38	5.98	12.45	8.80	3.74	282	144	
100	0.213	5.23	2.80	8.09	14.48	5.48	1.6	254	237	208
	0.226	4.90	1.00	7.62	15.50	6.14	1.98	240	200	
	0.233	4.60	0.55	7.12	15.52	7.56	2.36	224	193	
	0.270	4.20	0.42	6.50	13.88	8.08	3.42	205	170	

Load										
200	0.220	4.92	3.22	6.82	13.90	5.66	1.3	230	236	197
	0.233	4.76	1.06	6.61	15.72	5.98	1.72	222	187	
	0.253	4.68	0.65	6.47	14.40	8.88	2.62	216	161	
	0.276	4.60	0.58	6.38	13.32	8.86	3.80	212	142	
300	0.226	6.50	3.54	8.75	13.88	5.80	1.21	238	180	166
	0.240	5.64	1.61	7.59	14.92	6.30	1.62	206	165	
	0.267	5.41	0.85	7.28	14.25	6.90	2.16	197	148	
	0.280	4.46	0.62	6.00	13.02	9.08	3.56	163	130	
400	0.250	6.42	3.77	7.32	13.38	6.00	0.94	199	160	159
	0.256	6.04	2.31	6.88	14.34	7.16	1.28	188	153	
	0.263	5.26	0.90	6.00	14.06	8.78	2.32	165	136	
	0.285	4.52	0.54	5.16	12.86	9.18	3.80	141	121	
500	0.266	5.14	3.70	8.06	13.60	6.20	0.64	163	143	155
	0.273	4.81	2.10	7.54	14.30	7.10	1.10	151	132	
	0.286	4.26	1.20	6.68	14.10	8.59	2.27	134	121	
	0.293	3.98	0.87	6.12	12.80	9.10	3.60	126	105	
600	0.280	4.59	3.18	8.46	14.16	6.16	0.36	182	151	144
	0.300	3.91	2.11	7.20	14.29	7.15	1.21	157	137	
	0.310	3.65	1.27	6.74	14.18	8.64	2.22	145	123	
	0.320	3.26	0.88	6.00	12.26	9.24	3.98	130	100	

Table 4.16

Mass Emission Rate in Converter on Genset, LG 700K Model, with Secondary Air Injection by Blower, Ambient Temperature = 25° C

Load, Watts	Air Flow Rate L/Sec	CO, g/hr		HC, g/hr		Max. Eff.	
		In	Out	In	Out	CO	HC
Idle	0.187	225	1.06	0.65	0.44		
	0.200	225	51.9	0.65	0.41		
	0.226	225	17.3	0.65	0.39		
	0.260	225	14.8	0.65	0.29	93.42	55.38
100	0.213	213	88.1	0.52	0.37		
	0.226	213	32.9	0.52	0.33		
	0.233	213	18.6	0.52	0.33		
	0.270	213	15.9	0.52	0.32	92.53	38.46

200	0.22	240	108.0	0.56	0.39		
	0.233	240	36.3	0.56	0.32		
	0.253	240	24.8	0.56	0.31		
	0.276	240	23.9	0.56	0.29	90.00	48.21
300	0.226	290	138.5	0.53	0.35		
	0.24	290	66.4	0.53	0.32		
	0.267	290	38.4	0.53	0.33		
	0.280	290	30.9	0.53	0.32	89.34	39.62
400	0.250	332	156.4	0.52	0.33		
	0.256	332	98.7	0.52	0.32		
	0.263	332	42.8	0.52	0.32		
	0.285	332	37.7	0.52	0.31	88.60	40.38
500	0.266	284	156.4	0.45	0.30		
	0.273	284	93.5	0.45	0.29		
	0.286	284	57.2	0.45	0.28		
	0.293	284	26.4	0.45	0.28	83.66	37.77
600	0.280	276	144.1	0.55	0.34		
	0.300	276	101.1	0.55	0.32		
	0.310	276	64.6	0.55	0.31		
	0.320	276	52.6	0.55	0.31	80.91	43.63

Table 4.17

Measured and stoichiometric secondary air requirement for maximum conversion

Load, Watts	Secondary Air, Liter/Sec.		
	Stoichiometric	Measured for (CO) conversion	Measured for (HC) conversion
Idle	0.276	0.260	0.260
100	0.306	0.270	0.270
200	0.316	0.276	0.276
300	0.336	0.280	0.280
400	0.358	0.285	0.285
500	0.393	0.293	0.293
600	0.434	0.320	0.320
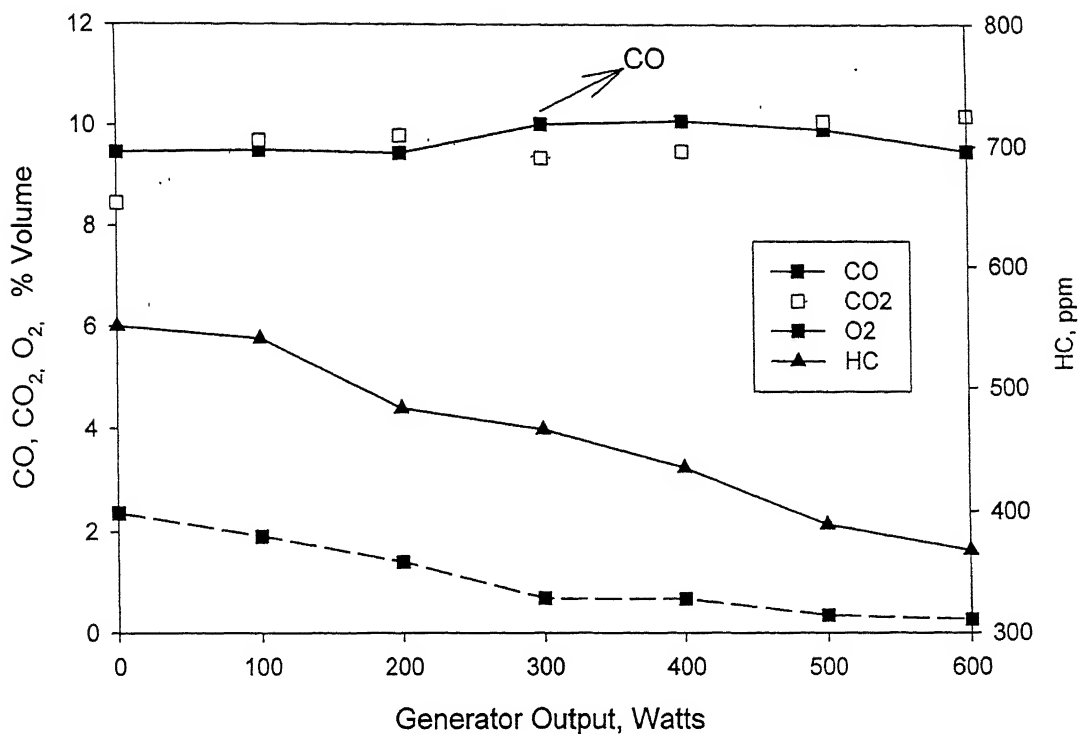
Fig: 4.1 Exhaust gas composition at inlet to converter on Genset,
         without secondary air.
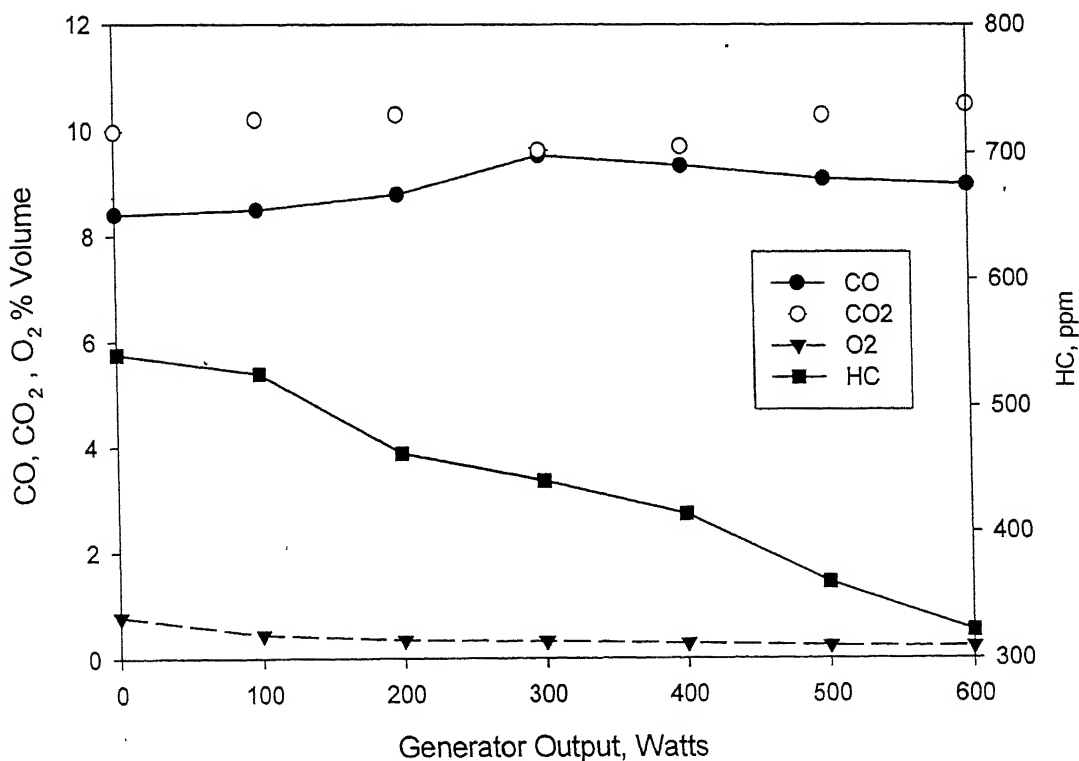
Fig: 4.2 Exhaust gas composition at outlet to converter on Genset,
         without secondary air.
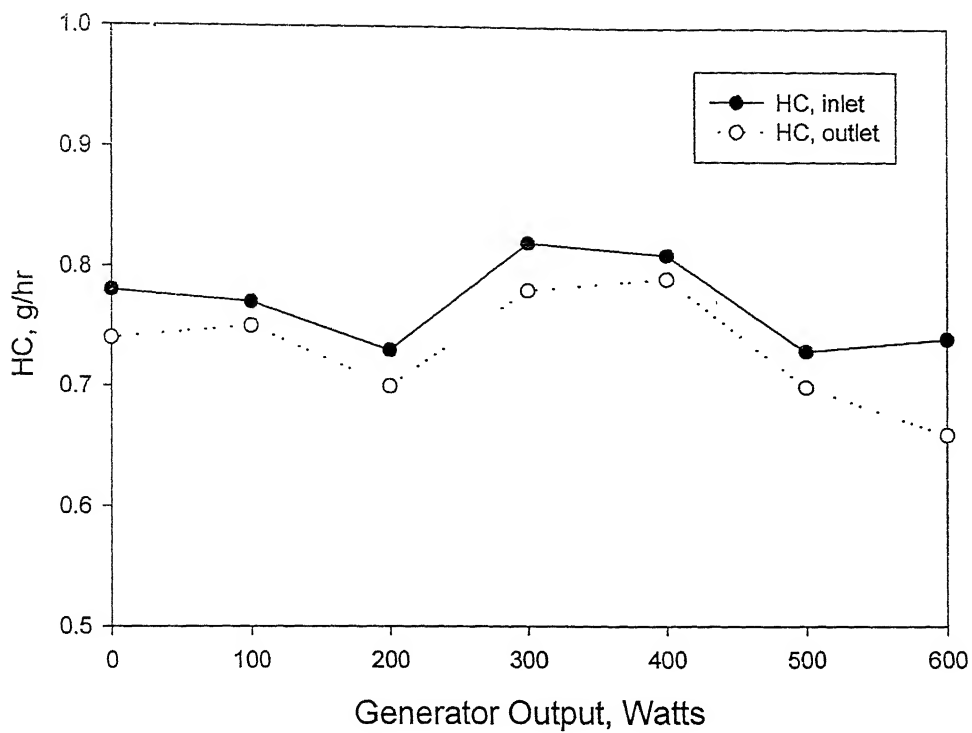
Fig: 4.5 HC at the converter on Ganset, without secondary air.
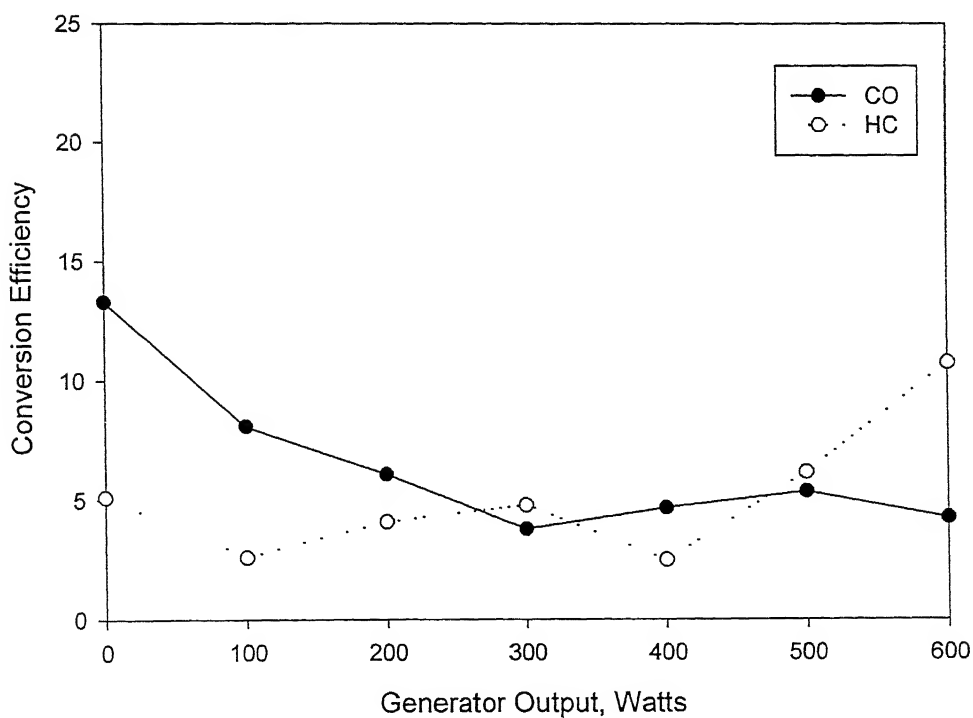
Fig: 4.6 Catalytic conversion efficiency for CO and HC at different loads, without secondary air.
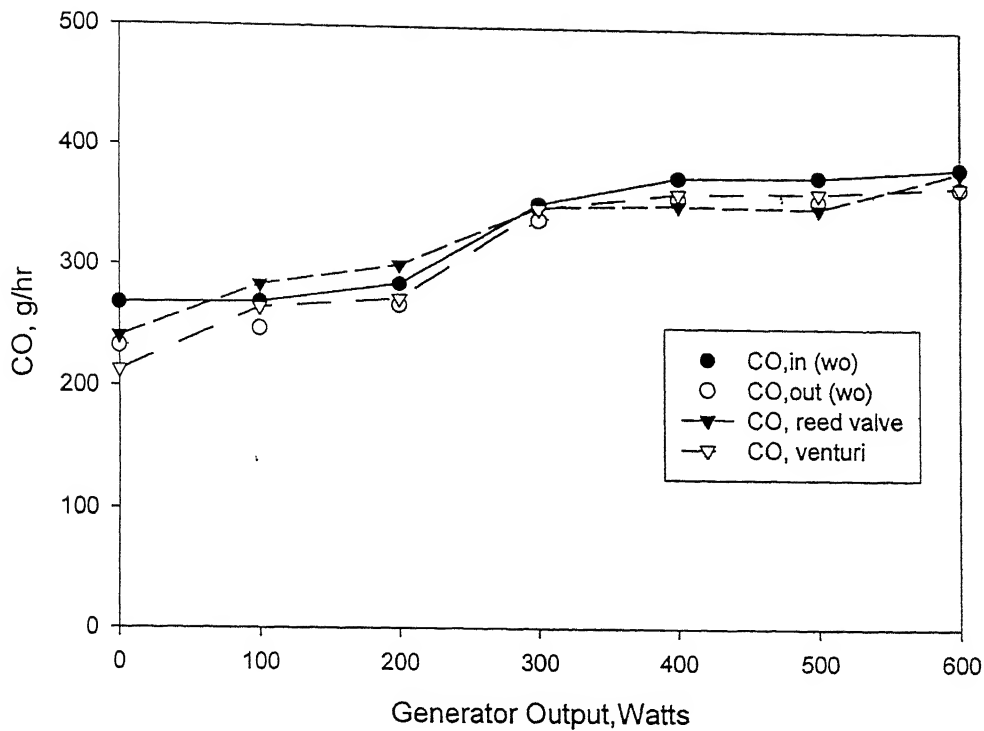
Fig: 4.7 Converter performance for CO at different loads,
with different secondary injection methods
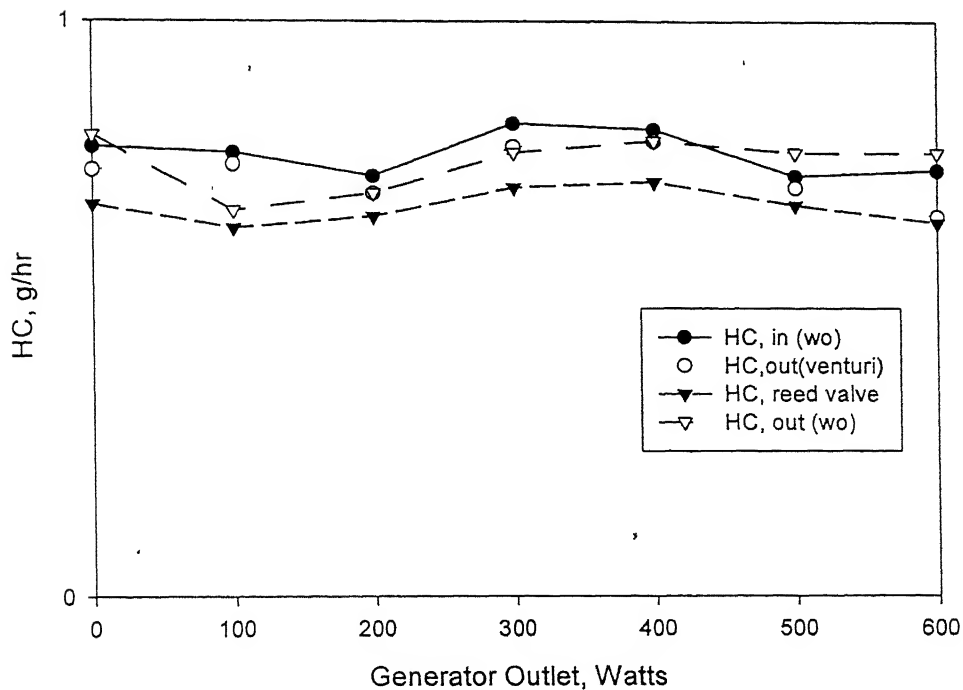
Fig: 4.8   Converter performance for HC at different loads,
with different secondary air injection methods
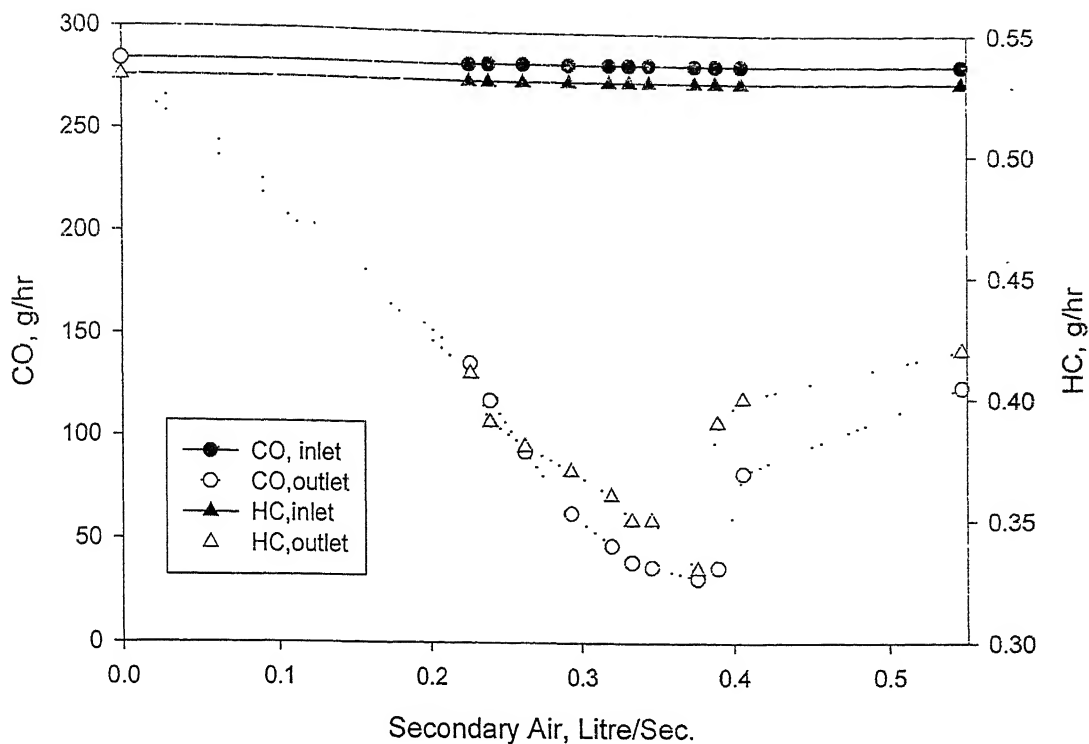
Fig: 4.9   Conversion of CO and HC at load 300W,
with different secondary air
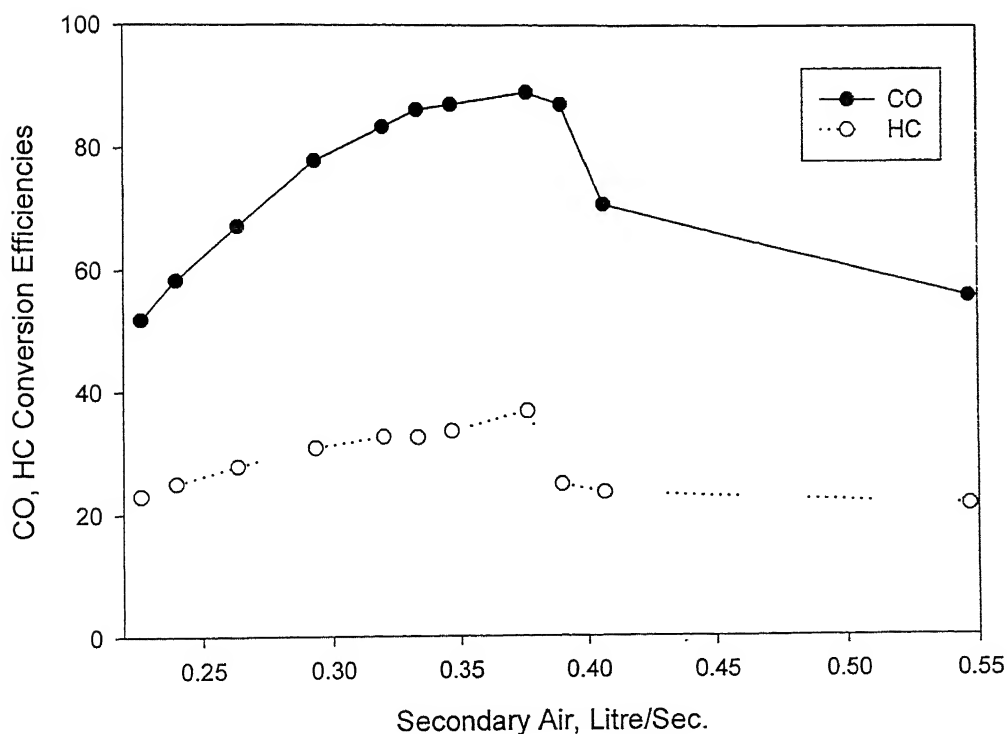
Fig: 4.10 Catalytic converter efficiencies for CO and HC with different
secondary air at 300W
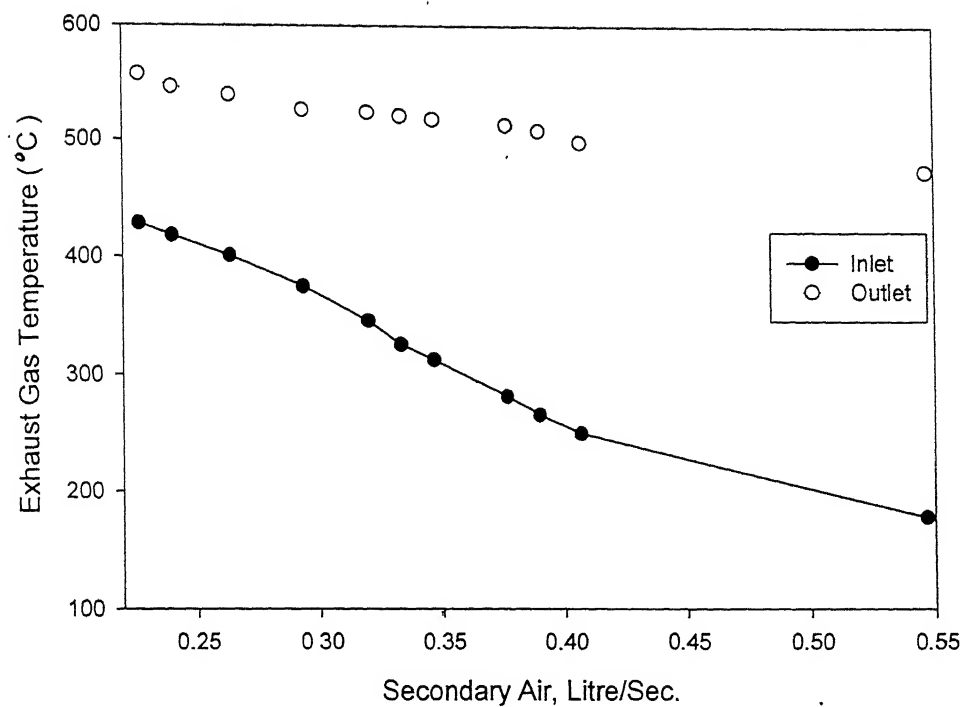
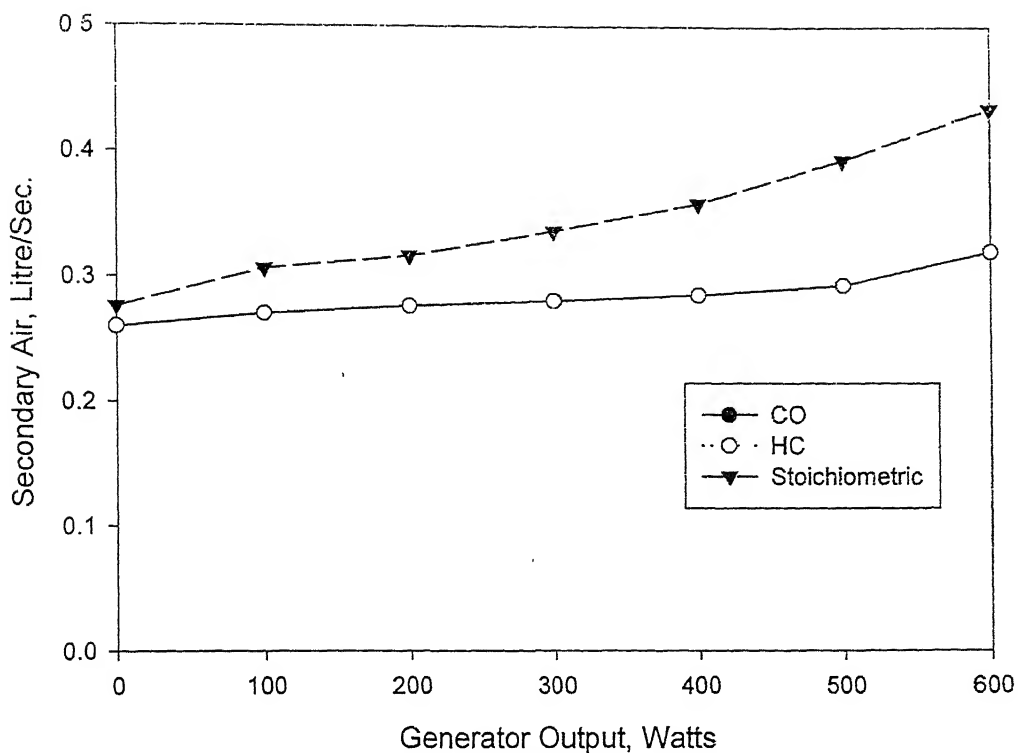Fig: 4.11 Exhaust gas temperature variation with secondary air,
at load 300W .
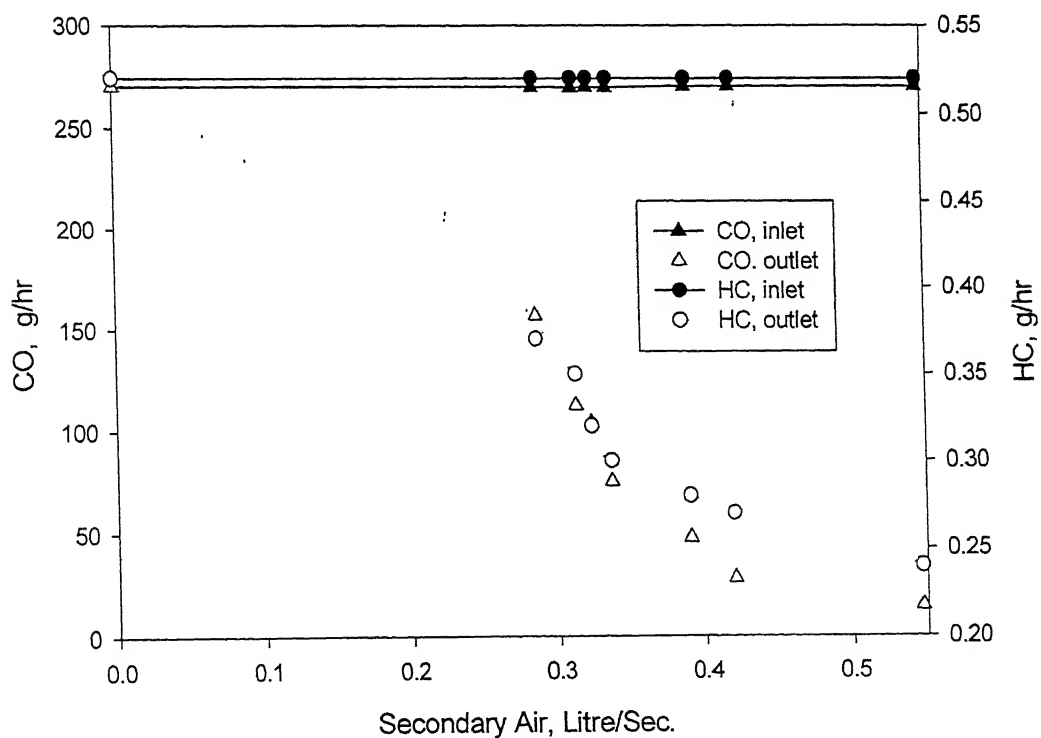
Fig: 4.12 Conversion of CO and HC at load 600W,
with different secondary air
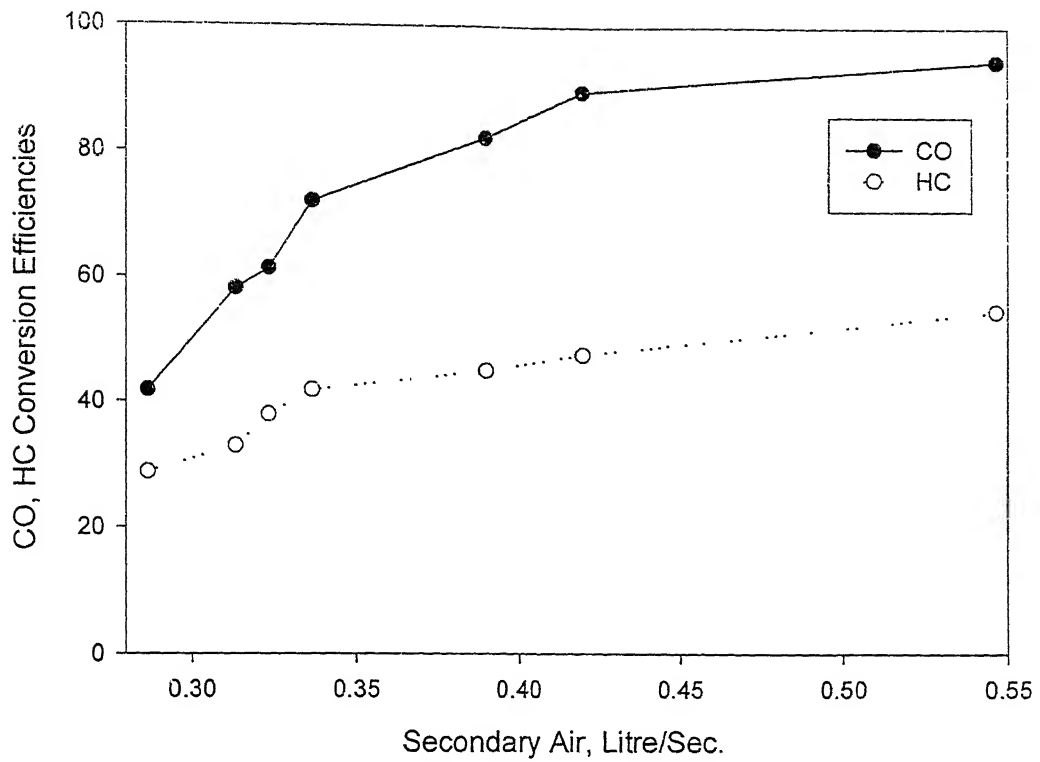
Fig: 4.13 Catalytic converter effienciencies of CO and HC at load 600W, with different secondary air
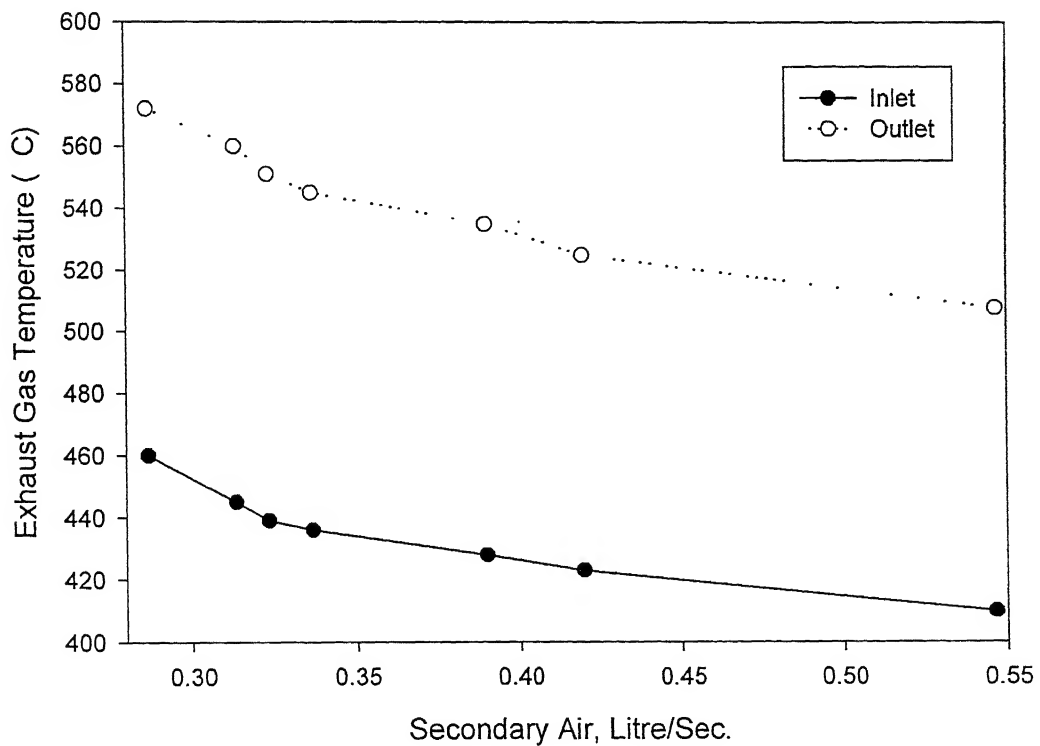
Fig: 4.14 Exhaust gas temperature variation with secondary air, at load 600W

Fig: 4.15   Stoichiometric requirements of secondary air for complete oxidation
of CO and HC and actual seconadry air requirement for maximum
conversion of CO and HC, at different loads.
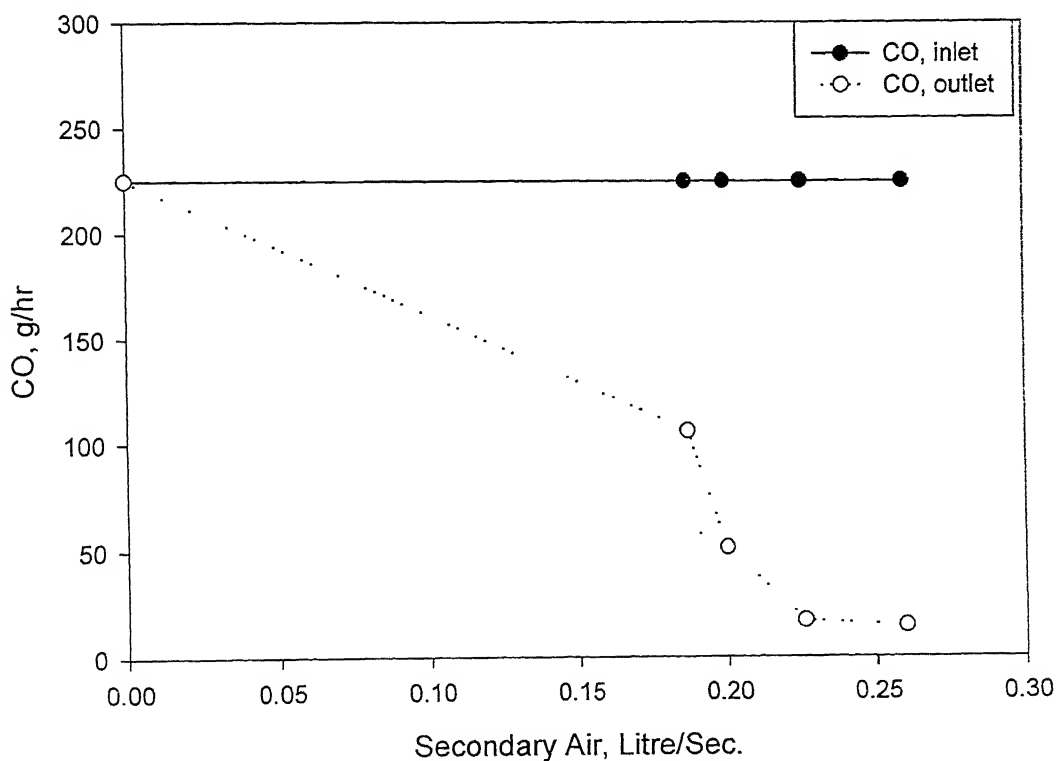
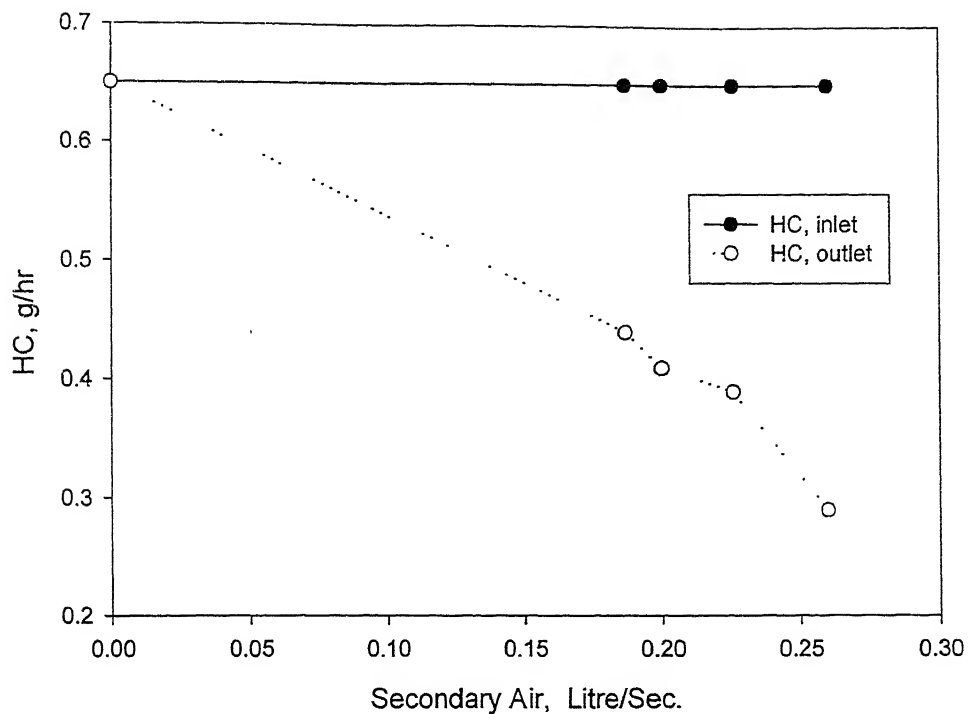Fig: 4.16   Conversion of CO in converter on Genset at Idle load,
with secondary air.

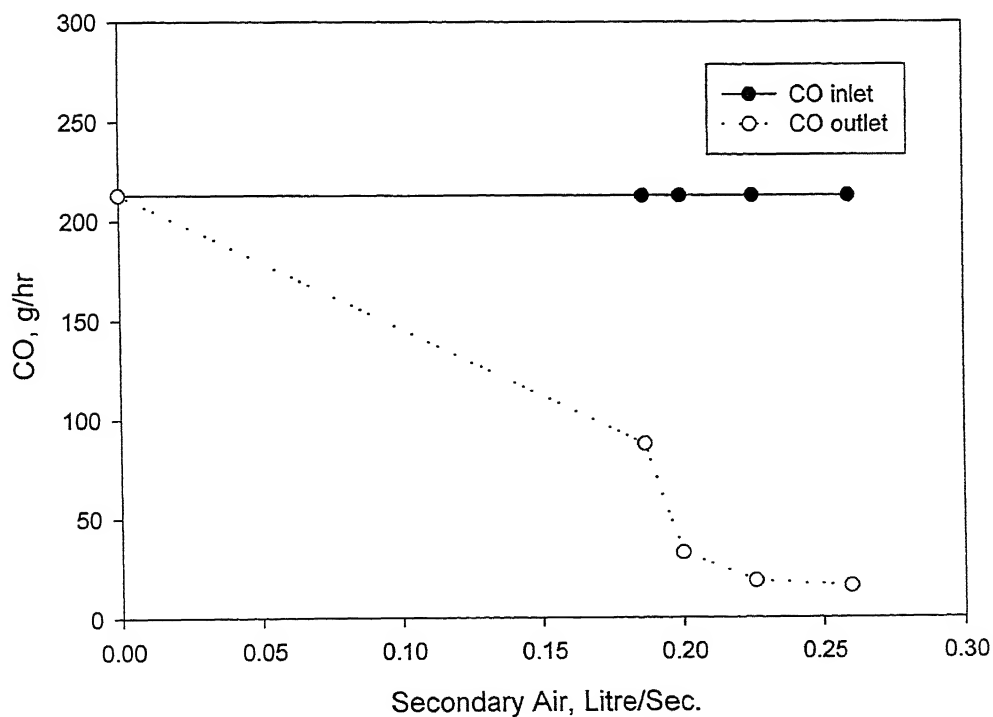Fig: 4.17 Conversion of HC in converter on Genset at Idle load, with secondary air.

Fig: 4.18 Conversion of CO in converter on Genset at 100 Watts, with secondary air.
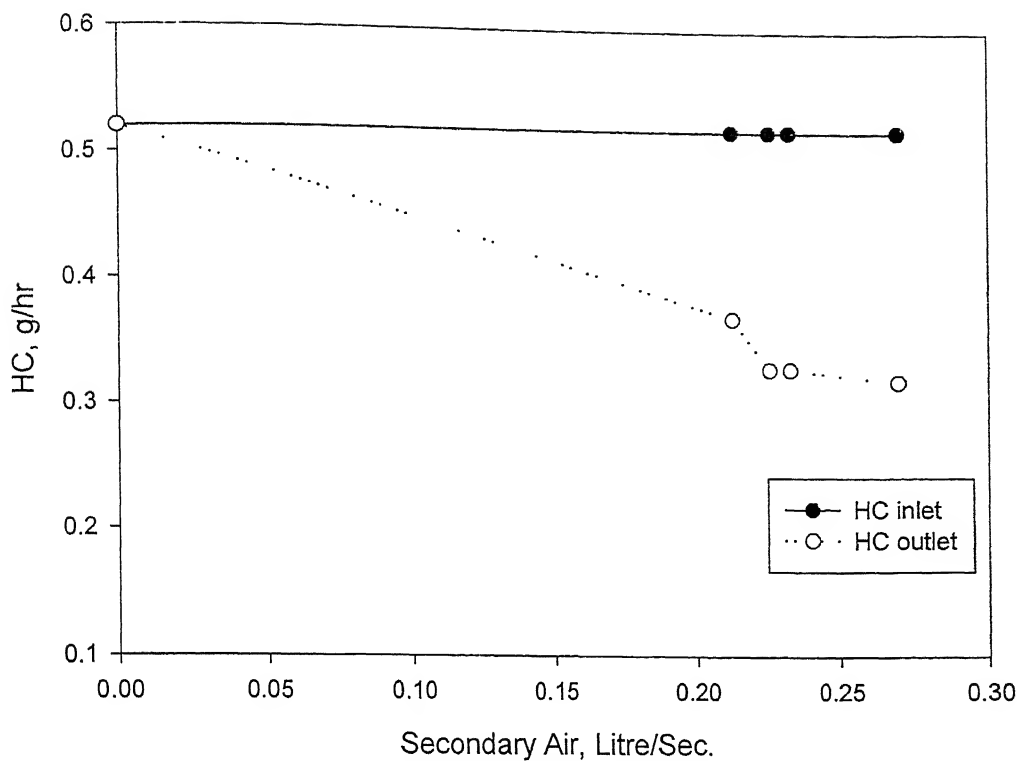
Fig: 4.19 Conversion of HC in converter on Genset at 100 Watts, with secondary air.
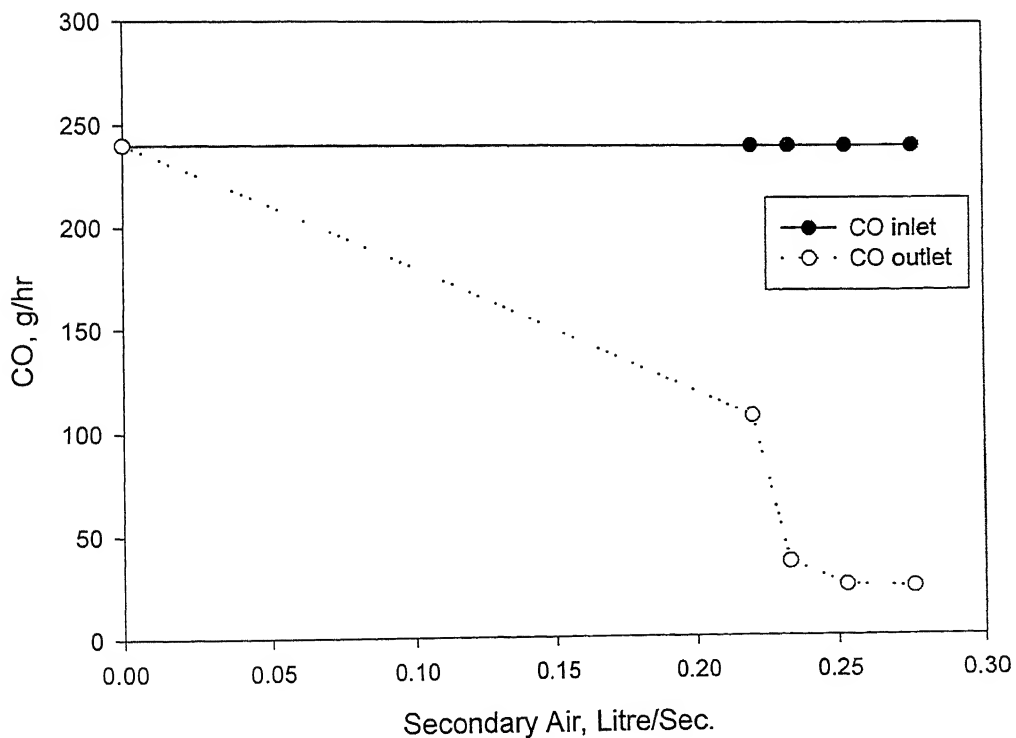

Fig: 4.20 Conversion of CO in converter on Genset at 200 Watts, with secondary air.
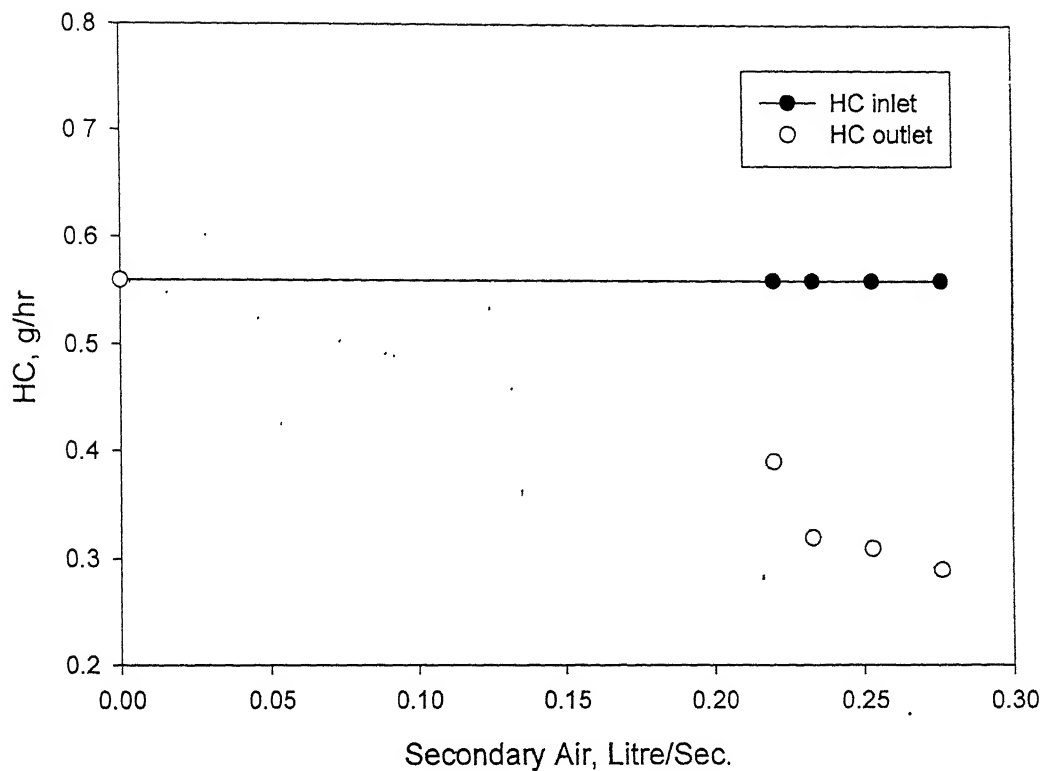
Fig: 4.21 Conversion of HC in converter on Genset at 200 Watts, with secondary air.
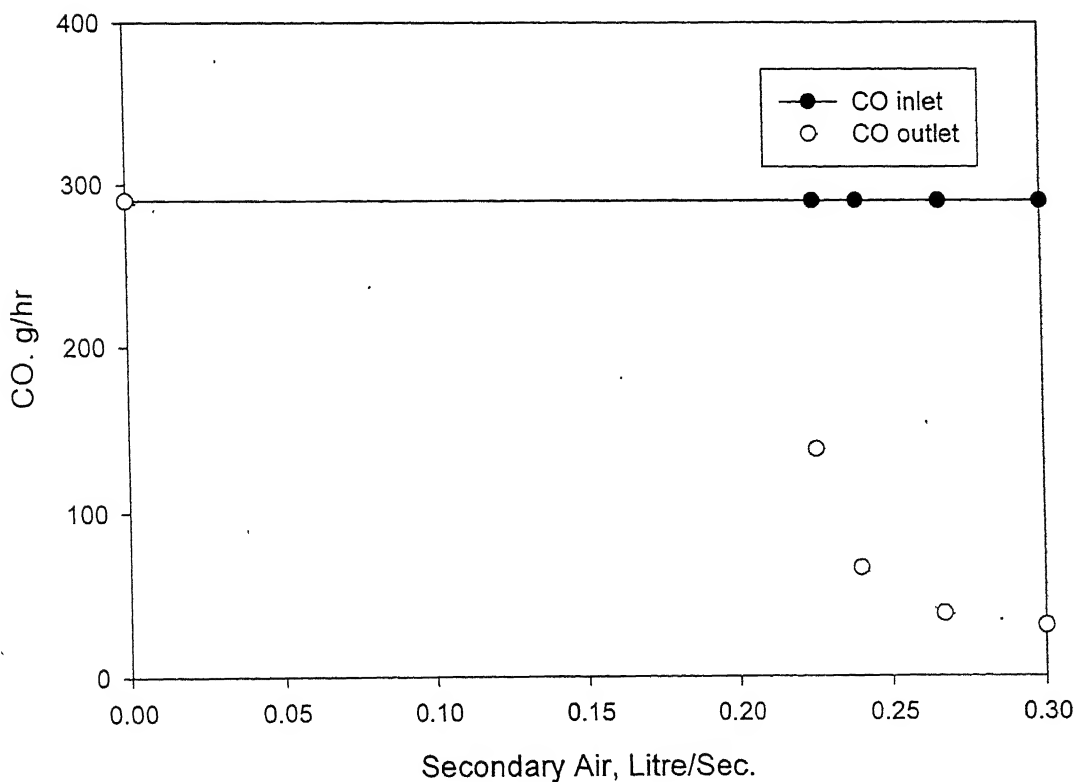

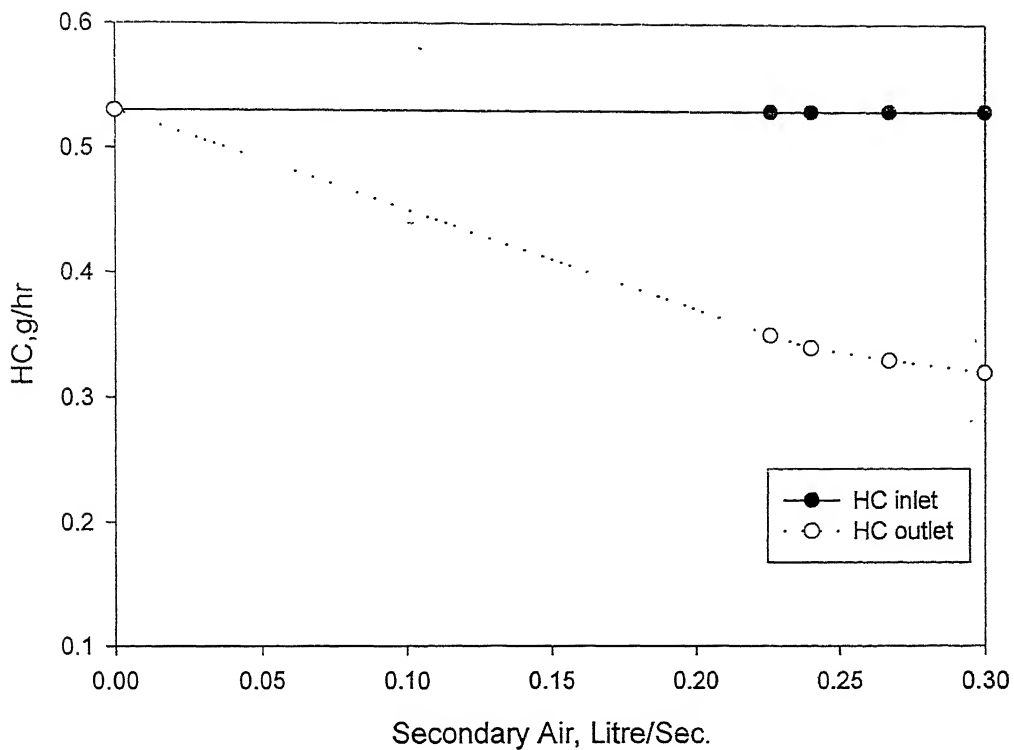Fig: 4.22 Variation of CO in converter at 300 watts on Genset.

Fig: 4.23 Conversion of HC in converter on Genset at 300 Watts, with secondary air.

Fig: 4.24 Conversion of CO in converter on Genset at 400 Watts, with secondary air.

Fig: 4.25 Conversion of HC in converter on Genset a 400 Watts, with secondary air.
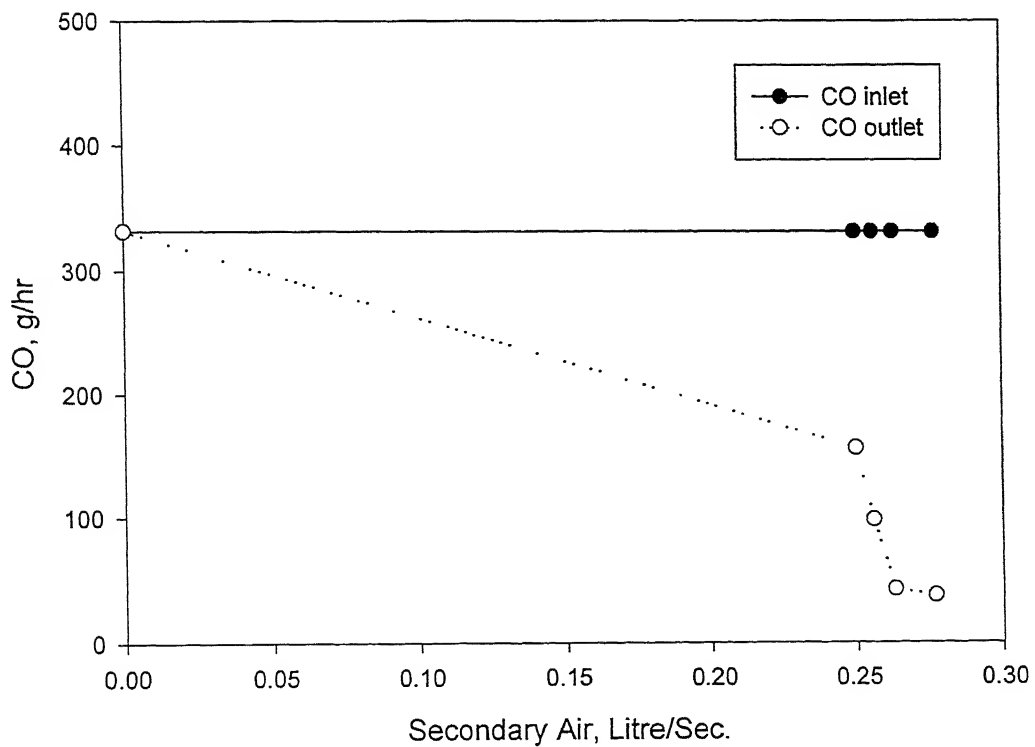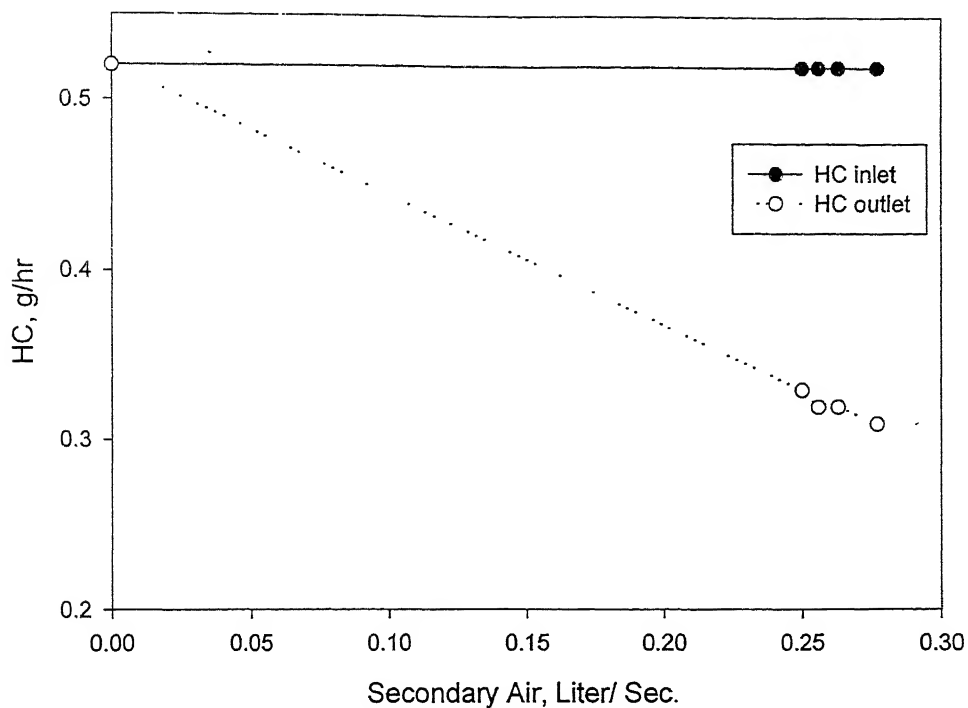

Fig: 4.26 Conversion of CO in converter on Genset at 500 watts with secondary air.

Fig: 4.27 Conversion of HC in converter on Genset at 500 Watts, with secondary air.

Fig: 4.28 Conversion of CO in converter on Genset at 600 Watts, with secondary air.

Fig: 4.29 Conversion of HC in converter on Genset at 600 Watts,
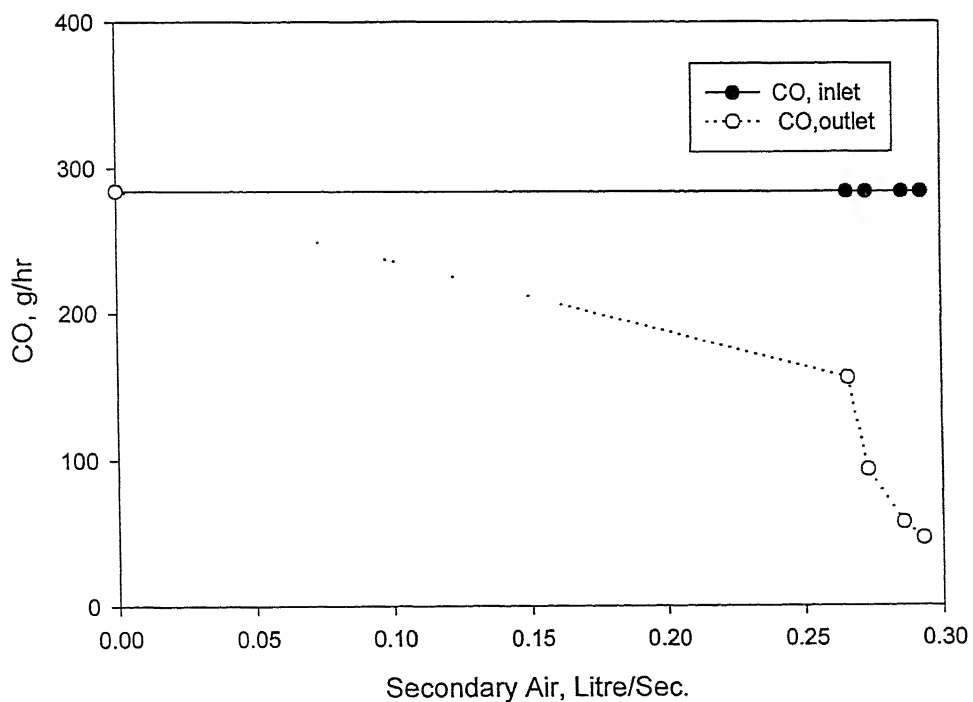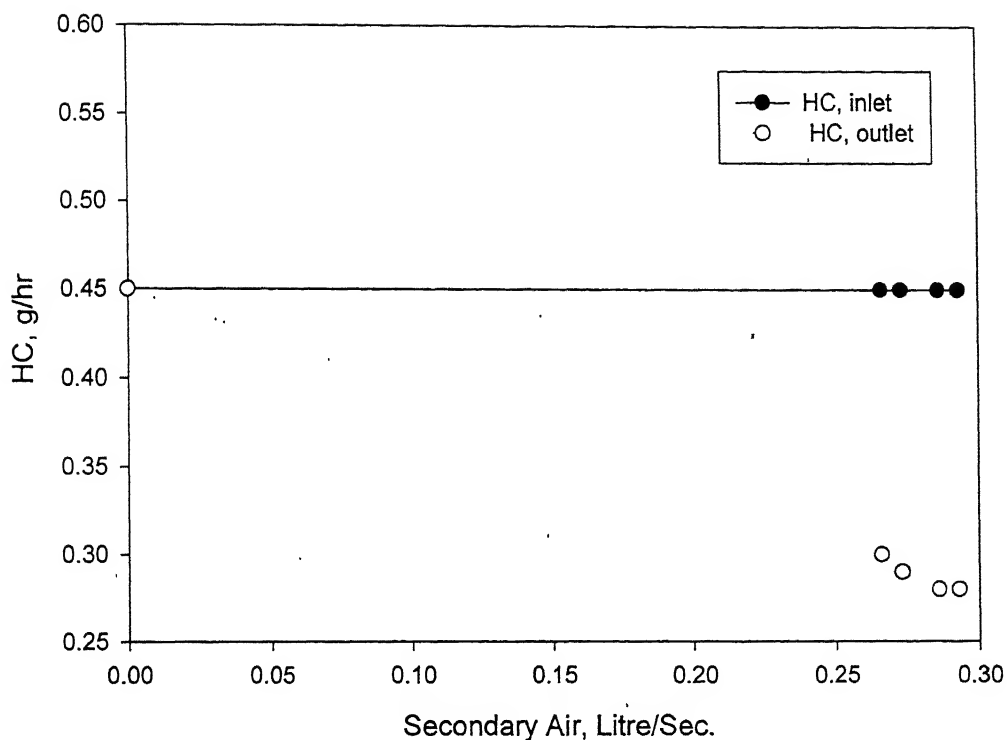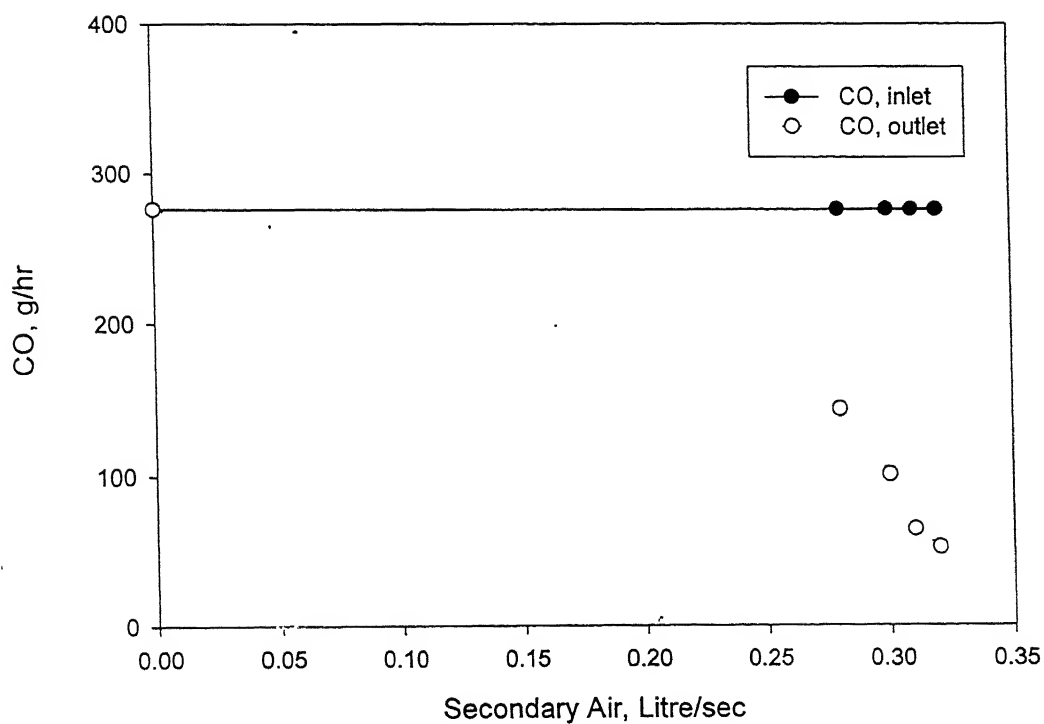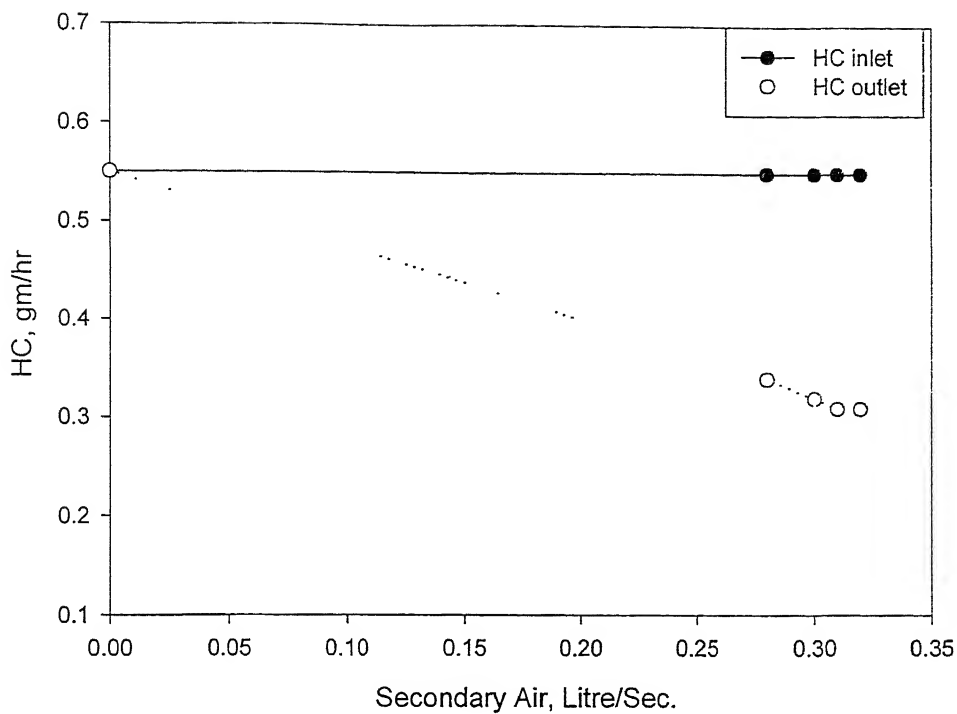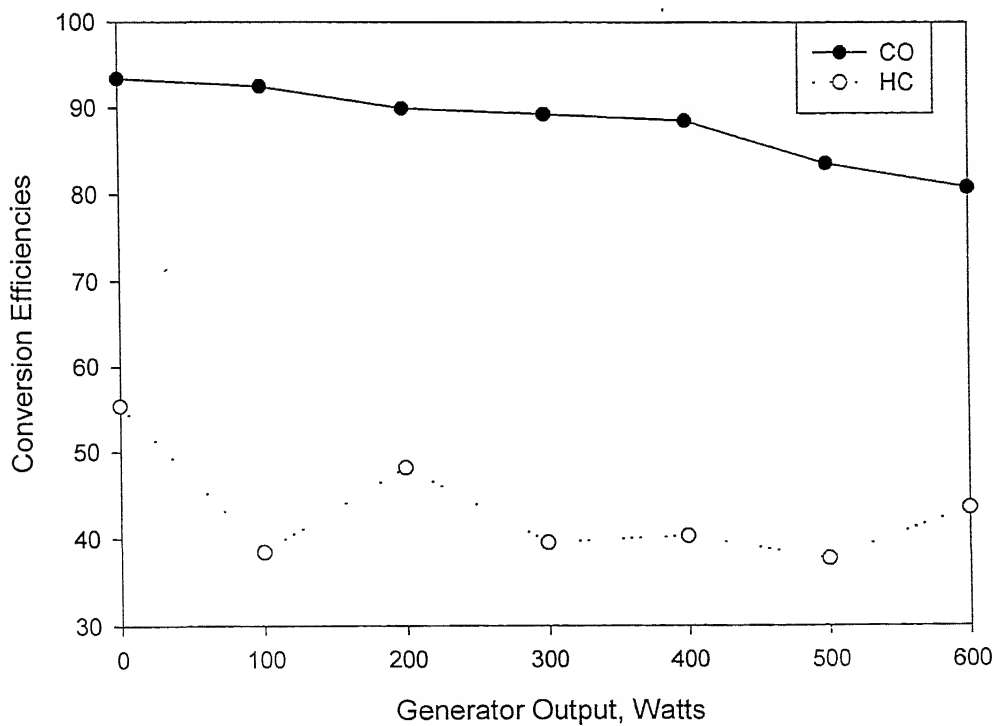with secondary air.

Fig: 4.30 Variation of conversion efficiencies (maximum)of CO and HC
in converter on Genset at different loads,with secondary air.

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CHAPTER 5

CONCLUSIONS:

Test on Kerosene fuelled 4-stroke SI engine generator set show;

1. Engine operates very rich with air-fuel ratio in the range 10 to 10.9: 1 only.

2. Without using the secondary air there is hardly any oxidation of CO and HC by the converter due to deficiency of oxygen in the exhaust. The conversion efficiency was observed to be less than 4%.

3. Without using the secondary air and catalyst, emissions of CO emission range 268.2 g/hr to 385-g/hr and HC 0.73 g/hr to 0.82 g/hr.

4. Use of the reed valve or venturi in the exhaust pipe did not succeed in introducing sufficient secondary air to obtain significant CO and HC oxidation.

5. With the use of a blower to inject secondary air, catalytic reduction of CO and HC emissions down to 14.8 g/hr to 156.4 g/hr and 0.28 g/hr to 0.44 g/hr respectively.

6. The conversion efficiency using secondary air with metal monolith converter for CO varies from 80.91% - 93.42%, which is quite high, for HC conversion efficiency varied from 37.77% - 55.38%. The HC emissions even without catalyst were quite low, as engine is a 4-stroke engine.

7. Further studies on the optimization of secondary air and engine carburation should be able to introduction system result in building a commercially viable product.

8. Use of reed valve successfully requires further studies to identity proper location in the exhaust pipe where vacuum during part of exhaust process due to reflection of pressure wave results. Also, may be a special reed valve with less stiff reed is required

Scope for Future Work:

1. Development of a compact, low cost secondary air induction system.

2. Catalytic converter durability studies on kerosene gensets, as very little information is available on application of catalytic converter on such appliances.

Appendix:

Sample Calculation of Monolith Catalytic Converter, on 4-stroke Petrol start Kerosene run generator, Model 700K, at 400W.

Calculations without induction of Secondary Air:

Mass flow rate of fuel in g/hr, G_F = 366.97

Avg. dry concentration of exhaust gases;

	Inlet	Outlet
CO, % vol	10.1	9.33
CO2, % vol	9.50	9.72
HC, ppm	435	414
$H_2\%_d$	5.13	4.62
K	0.873	0.874

Avg. wet concentration of exhaust gases;

	Inlet	Outlet
CO, % vol	8.82	8.15
CO2, % vol	8.29	8.49
HC, ppm	380	361.78
TC	17.15	16.68

Mass emission in g/hr,

	Inlet	Outlet
CO	376.1	358.11
HC	0.81	0.79

Mass emission in g/kW-hr,

	Inlet	Outlet
CO	941.93	895.28
HC	2.03	1.98

Conversion Efficiency;

CO	4.7%
HC	2.5%

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